The PHOROPTOR

Its Use In Ocular Refraction

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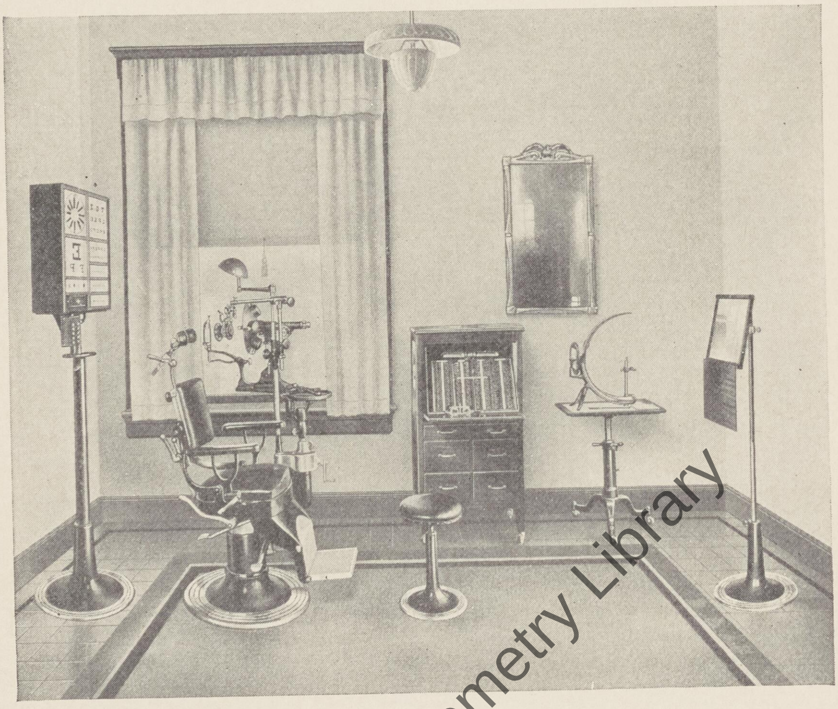

Wellsworth Complete Ideal Refracting Room

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The Improved Wellsworth DeZeng Phoroptor

and its use in Ocular Refraction

Profusely Illustrated

Published by
The Division of Ocular and Professional Interests
American Optical Company
Southbridge, Massachusetts, U.S.A.

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PREFACE

OCULAR refraction is both a science and an art. As a science, it consists of the great body of facts relative to the physiology of vision: these facts, as transmitted to us through the writings of Donders, Helmholtz, Javal, Landolt, Knapp and others who have gone "to join the innumerable caravan that moves to that mysterious realm", have formed the foundation upon which has been built the modern science of ocular refraction. And these facts are being added to almost daily by the ever-growing numbers of those who are interested in human vision, particularly in the errors of refraction and the anomalies of accommodation and binocular single vision. As an art, it consists in the skill with which those who practice in any manner upon the human eye put into daily application the principles of ocular science to the end that human eyes may carry on their natural functions with the best possible acuity of vision and with the least wear and tear upon the nervous system, of which the eyes are so intimate and important a part.

History is replete with illustrations of the fact that progress in scientific knowledge goes hand in hand with the development of improved apparatus. Acquisitions of new knowledge and the devising of new equipment have not just "happened" or "growed" like Topsy, but they have come as the result of many years of experimentation and investigation. It is a long way from the candle to the modern variegated and efficient forms of illumination; it is a long way from the huntsman's hut to the modern palatial home; it is a long way from the "Stourbridge Lion" to the powerful, smooth running "horse of iron" of today. Just as far, proportionately speaking, between the hand retinoscope, hand ophthalmoscope and the old style of trial case of years ago to the present day perfected instruments.

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Just as a man is known by the company he keeps, just as truly is the workman known by his tools and the way in which he uses them. Living at the close of the first quarter of the twentieth century, no one has any notion of reading the evening newspaper by candlelight, housing himself and family in a log hut and otherwise conducting himself as a "has been". Surely it is of as great, if not greater, importance that one surround himself in his chosen field of work with the best of equipment, in order that data may be accurately and intelligently obtained and with ease and comfort both to the patient and to himself.

A well-known writer upon the technic of refraction has said so aptly: "After all is said and done, the practical end of ocular refraction consists in its technique, that is to say, in the most skillful and efficient application to the case in hand of the methods and apparatus at one's disposal, and the most intelligent evaluation of the findings". An intelligent evaluation of findings presupposes data accurately and intelligently obtained. Accurate and intelligent data presuppose accurate instrumentation.

It is presumed, therefore, that the reader of this brochure on *Phorometry and the Phoroptor* is imbued with the true spirit of science and that he is desirous of serving those who come to him for his attention and care, with a wealth of knowledge inherited and acquired from the investigators of the past as well as of the present, and with equipment which makes possible the practical application of this knowledge to the pair of eyes under examination.

For, as David Grayson says: "We are all, more or less, amateur philosophers, but we would be poor scientists indeed if our 'views' were permitted to color our facts. Phenomena, as they appear today, are set out for the critical examination of the student. He will have all the facts and the circumstances fully mobilized, standing up side by side before him like an awkward squad, and there

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is nothing more awkward than some facts that have to stand out squarely in the daylight. And he inquires into their ancestry, makes them hold out their tongues and pokes them once or twice in the ribs, to make sure that they are lively and robust facts capable of making a good fight for their lives. He never likes to see one thing too large, lest he see something else too small; but he will have everything in true proportion."

The American Optical Company believes that its Wellsworth DeZeng Improved Phoroptor is a contribution of distinct value to those whose life-work lies in the field of ocular refraction, for 'everything is in true proportion' and thereby is made possible, as never before, skill, accuracy and efficiency in the art and science of investigating the needs of human eyes, to the end that every pair of eyes thus examined may be so taken care of as to economically coördinate the functions of distinctness of vision, accommodation and convergence.

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CHAPTER I

THE EVOLUTION OF OCULAR SCIENCE AND THE DEVELOPMENT OF SCIENTIFIC INSTRUMENTS FOR OCULAR EXAMINATION

As Professor Gage[1] in his book on *The Microscope* says:—"It is impossible to think of a world without lenses. All apparatus, like the moving picture machine, magic lantern, photographic camera, the microscope and telescope and spectacles, would be no more * *. What immeasurably great insight into the real world has come with those 'optic glasses'! What revelations as to the cause of disease, of the structure of the universe in its smallest details by the microscope and in its largest ranges by the telescope: and greatest of all, for the common man, has come the power, by means of spectacles, to make good use of the years that hygiene has added to the average human."

Simple as a lens really is, it took several centuries of time after the birth of Christ before the first clear and unmistakable statements were made and from which have arisen our modern ideas of lenses and their action. Presumably the credit is to be given to Roger Bacon. In the first and second centuries of the Christian era there was an abundance of knowledge of mathematics and of optics to make possible the invention of the simple microscope. Every convex lens is or may be used as a simple microscope as it aids the eye in seeing an object under an increased visual angle, and hence makes it appear larger than it would if viewed by the unaided eye. The date of the invention is sometime before the date of the *Opus Majus* (1266–1267) of Roger Bacon. Bacon referred to them as one of the means whereby wonderful things could be accomplished and endeavored to induce the Church to give the furthest support to science in order that

[1]Gage, Simon Henry. *The Microscope*, The Comstock Publishing Company, Ithaca, New York.

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the Christian world might be the leader in advancing civilization. Nowhere does he claim to be the inventor of lenses, but he expounded the principles upon which they worked and referred back to Ptolemaeus (70–147 A. D.) for laws of refraction. Bacon tells us that much of his private fortune was spent in obtaining apparatus of all kinds, for he believed that "the final test of science is experiment."

Bacon demonstrated that convex lenses made it possible for old men—for women and their right to education and

VISION
HEARING
TOUCH
SMELL
TASTE

Fig. 1. The order of importance of the physical senses.

to read was not even dreamed of in those days—to read the smallest letters. Within less than fifty years from that time (1299 A. D.) there is to be found in a manuscript this sentence:—"I am so affected by years that I cannot read or write without the glasses they call spectacles, lately formed for the benefit of old men when their eyesight gets weak".[2]

At what time man invented lenses and discovered the aid which they are capable of lending to vision is a matter beyond our knowledge.[3] The tomb of Salvinus Armatus, a Florentine nobleman who lived in 1317, is said to bear an inscription to the effect that he was the inventor of spectacles.

[2]Shastid, Thomas H. *American Journal of Physiological Optics*, Vol. 7, p. 400, 1926. American Optical Company, Publishers.

[3]Glancy, A. Estelle. On the history of ophthalmic lenses. *American Journal of Physiological Optics*, Vol. V, p. 393, 1925.

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"Whoever the inventor, Alessandro di Spina, a monk of Florence, who died in 1313, is generally accredited with having made public the use of spectacles, and by several Florentine writers of that time we find him mentioned and recommended. Friar Jordan, of Pisa, in 1305 says that 'it is not twenty years since the art of making spectacles was found out and is, indeed, one of the best and most necessary inventions in the world'."[4]

Commenting on the history of spectacles and eyeglasses Shastid[5] says: "(1) Lenses of any sort or kind, as aids to vision, were wholly unknown to antiquity; (2) lenses were certainly not introduced into Europe from China; (3) the very first mention in history of the employment of lenses as a means of assisting the sight is that of Bacon; (4) the first inventor of spectacles is not known; (5) the re-inventor of spectacles was Alexander de Spina; (6) Salvino Armati had nothing to do with the matter; (7) by the middle of the fourteenth century, convex lenses and spectacle frames were in general use; (8) concave lenses began to be employed about the beginning of the sixteenth century."

CYLINDRICAL LENSES

Improvement of spectacle lenses appears to have been slow. The world waited for more than two hundred years for another signal advance. In 1801 Thomas Young[6], to whom Sheard has applied the appellation "the father of physiological optics", discovered the defect of the eye known as astigmatism. He measured the astigmatism of his own eye with his optometer and expressed it, as we still do, by the difference of refraction in the two meridians. He had 1.70 D. of astigmatism "against the rule", which he demon-

[4]Phillips, R. J. *Spectacles and Eyeglasses.* P. Blakiston's Son & Co.

[5]Shastid, Thomas H. *American Journal of Physiological Optics*, Vol. 7, p. 580, 1926.

[6]Tscherning, M. *Physiologic Optics*, p. 121, Ed. 1904. Keystone Publishing Company.

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strated was not corneal in character and which he ascribed to the obliquity of the crystalline lens. It remained for George Airy, the astronomer of Cambridge University, to re-discover astigmatism, which he did in 1827. Airy had myopia in his right eye and a compound myopic astigma-

Fig. 2. Portrait of Thomas Young, "father of physiological optics" and the discoverer of astigmatism

tism in his left eye. Mr. Fuller, an optician of Ipswich, made, under Airy's direction, a concave sphero-cylindrical lens which satisfactorily corrected his error. Later Colonel Goulier studied this defect and prescribed cylindrical glasses to a certain number of patients. It was only after the invention of the ophthalmometer by Helmholtz that the measurements of Knapp and Donders drew attention to this prevalent anomaly in the human eye. Donders (who wrote the classic on *The Anomalies of Refraction and Accommodation*, which was published in 1864) was the first to have cylindrical lenses put in the trial case.

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Until the introduction of cylindrical lenses for spectacle wear, ophthalmic apparatus was of the crudest and consisted mainly of sets of pairs of spherical lenses fitted into horn frames known as "tiers". With the advent of the cylindrical lens and the necessity for the rotation of the lenses, came the full trial case, the ophthalmoscope, the ophthalmometer and retinoscope.[7]

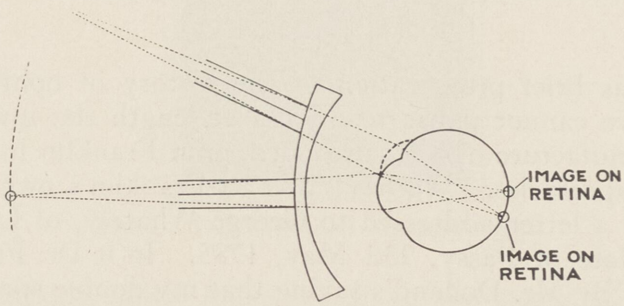

Fig. 3. The Wellsworth Tillyer lens and its points of superiority

From the day of these crude lenses to the present time there has been an ever upward progress in ophthalmic lenses. For we have had the periscopic, the meniscus and toric forms, until today we are possessed of the Wellsworth Tillyer lens, of which the power is measured in terms of effective or vertex refraction—the only truly scientific system or method, for it is based upon the value of the so-called back focal length of the lens as measured from a point on the ocular surface of the lens and lying upon the principal axis. Of this lens Homer E. Smith writes[8]:—"The A. O. Co. in the Wellsworth Tillyer lens has reached the happy medium and has so correlated the flexures (*i. e.* dioptric powers of the surfaces)[9] that the residual marginal errors are negligible and at the same time there has resulted a lens of graceful proportions."

[7]Glazebrook, Sir Richard. *Dictionary of Applied Physics.* Vol. IV, p. 280, 1923. Macmillan & Company.

[8]Smith, Homer E. *Applied Refraction.* Wm. Wood & Company, 1927.

[9]Material in parenthesis inserted by the writer of this brochure.

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A special feature of the Wellsworth DeZeng Improved Phoroptor Model 588 is the fact that proper compensation is made in the case of all lenses contained in the instrument, thus insuring the user that the total effective power at 13.75 mm in front of the ocular plane of the eyecups (*i. e.* at the normal prescription lens position) is the sum of all the lenses used, irrespective of the dial (and therefore distance from the eye) in which these may be placed.

BIFOCALS

In this brief presentation of the history of ophthalmic lenses we cannot pause to discuss at length the invention and manufacture of bifocals. Benjamin Franklin invented bifocal spectacles. We have this on Franklin's own statement in a letter addressed to George Whately, of London, under date of Passy, 23d May, 1785. In it Dr. Franklin says:—"By Mr. Dolland's saying that my double spectacles can only serve particular eyes, I doubt he has not been rightly informed of their construction * * *. I therefore had formerly two pairs of spectacles, which I shifted occasionally, as in traveling I sometimes read, and often wanted to regard the prospects. Finding this change troublesome and not always sufficiently ready, I had the glasses cut and half of each kind associated in the same circle."[10]

The orginal device of Franklin, which was slow in adoption, was not materially changed until the '60s, when the "solid upcurve" form was designed in America to be followed shortly by the "curved slit". In 1887 an improved form followed, called the "Perfection". In 1884 a new departure was made by using Canada balsam, and the cement bifocal was born. Then came the invention of Borsch in 1899 which resulted in the Kryptok or fused bifocal. Many have called this lens the "maker of modern professional refraction

[10]*The Complete Works of Benjamin Franklin.* Edited by John Bigelow, New York, 1888.

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and optical industry". This was followed by the solid or onepiece bifocals.[11] These fundamental forms of bifocals have been improved upon in various ways and with various

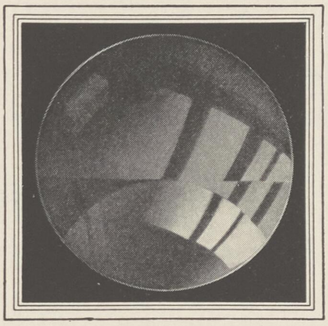

Fig. 4. The Wellsworth Monaxial bifocal

modifications, until today we have the perfected monocentric bifocal, the Monaxial. A distinctive product of the American Optical Company.

TRIAL CASE

Step by step with the progress in the art and science of the making of ophthalmic lenses have gone advancement and improvement in ways and means of testing the errors of refraction and the anomaly of accommodation. "The trial case, oddly enough, was invented by a general-practitioner-specialist, Fronmüller by name, and in the very identical year that saw the earliest sheet of test types, 1843."[12]

For nearly half a century the American Optical Company has manufactured and maintained the standard trial cases and sets of the world. Following the investigations of Charles F. Prentice in 1898, all standard trial case lenses were made to a specified center thickness and the curves of

[11]Taylor, Harry L. *Ophthalmic Bifocal Lenses.* Published by J. and H. Taylor, Birmingham, England, 1926. Bugbee, Louis W. *Bifocal Lenses.*

[12]Shastid, Thomas H. An outline history of ophthalmology. *American Journal of Physiological Optics*, Vol. 7, p. 395, 1926.

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the biconvex lenses were so modified that they were neutralized by the biconcave lenses which were, in turn, the master

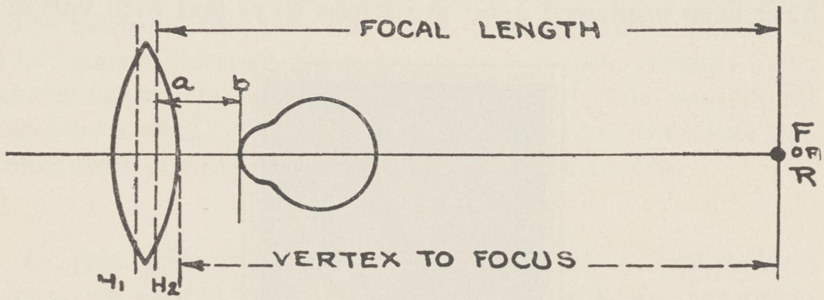

Fig. 5. Illustrating the principal planes and vertex refraction of a biconvex lens

lenses. As a result, therefore, standard biconvex lenses were actually made so that they conformed to the system of ver-

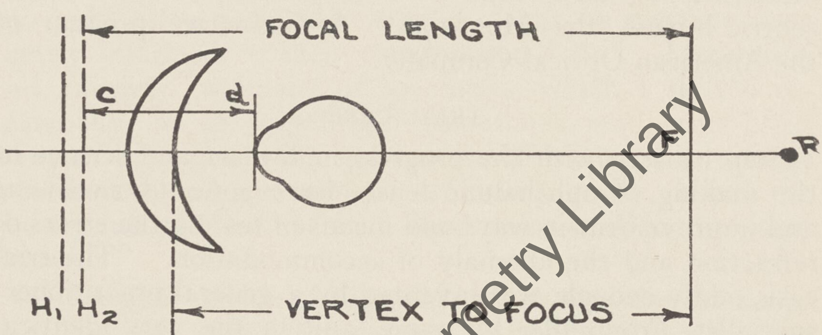

Fig. 6. Illustrating the principal planes and vertex refraction of a meniscus form of lens

tex refraction and all standard A.O.Co. trial case lenses are stamped with values which represent their dioptral powers in true vertex refraction units.[13]

[13]Glancy, A. Estelle. The power of a spectacle lens. *American Journal of Physiological Optics*. Vol. 2, p. 71, 1921.

Sheard, Charles. Principles of modern ophthalmic lenses. *American Journal of Physiological Optics*, Vol. 6, p. 32, 1926.

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THE DEVELOPMENT OF THE PHOROMETER AND PHOROPTOR

With a wealth of scientific development in ophthalmic lenses, test lenses, trial sets and frames behind him, Mr. Henry L. DeZeng patented a refractometer in the year 1895. This instrument marked some advance in both ease and accuracy in refractive work and served as the forerunner of later instruments such as the phorometer, phoro-optometer and Phoroptor.

At the beginning of the twentieth century, under the able guidance of such men as Howe, Savage, Stevens, Risley, Maddox, Prentice, and Thorington, refractionists awoke to the importance of a wider practical acquaintance with the motor apparatus of the eyes and the relationships between accommodation and convergence. Furthermore, retinoscopy (koroscopy, skiascopy, skiametry), the fundamental principles of which were laid down by Cuignet in 1873 and amplified and explained by Parent in 1880, was beginning to be accepted as an essential procedure. Its acceptance marked the era of equality, to say the least, of objective and subjective tests. Much has been done by Jackson,[14] Thorington,[15] Cross[16] and Sheard[17] to make various static and dynamic methods of skiametry valuable and necessary routine tests.

In large measure, the men whose names have been cited in the preceding paragraphs, as well as others not mentioned, were interested in the development of methods—the science of refraction. Mr. DeZeng in the very prime of life identified himself with such men and has devoted his life to an attempt to make practical instruments so that the science of refraction might also become an accomplished art and be turned

[14]Jackson, Edward J. *Skiascopy*, Herrick Book Co., Denver, Colo.

[15]Thorington, James. *Retinoscopy*, P. Blakiston's Son & Co.

[16]Cross, Andrew J. *Dynamic Skiametry in Theory and Practice.* Published by the author, 1912.

[17]Sheard, Charles. *Dynamic Skiametry*, Cleveland Press, 1920.

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from a theoretical science into a practical reality. In 1909 he presented to the profession his Phorometer trial frame containing cells to hold trial lenses for determining refractive errors, with appurtenances for making muscle tests. These consisted of the Stevens phorometer, Risley rotary prism and Maddox rod. Later two rotary prisms and two Maddox rods were embodied in the instrument. Thus began

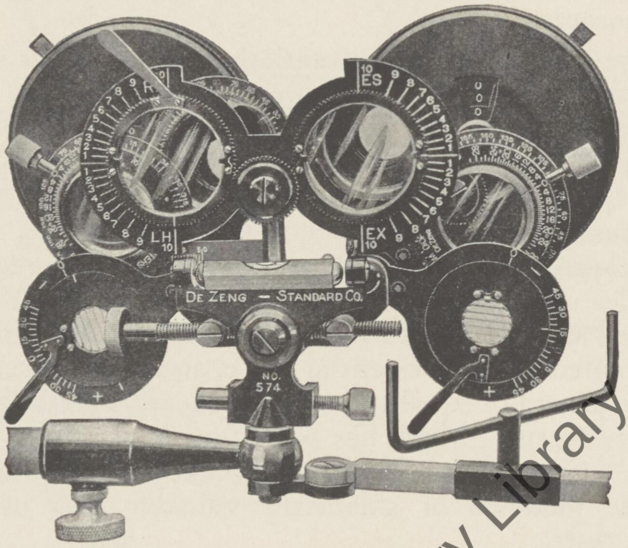

Fig. 7. The Phoro-optometer, No. 574, one of the signal inventions of DeZeng

the systematic testing of the extrinsic muscles of the eye and the routine procedure of making tests for heterophoria and measuring the ductions with fixation at twenty feet.

A few years later DeZeng added to his phorometric trial frame a battery of lenses, both concave and convex in character. Cylindrical lenses, when needed, were inserted from the trial case into a special cell attached to the front dial of the instrument. Thus was brought forth, through years of painstaking work and research, the Phoro-optometer—the first complete combination for refractive and

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muscular tests. The bulk of the original devices which were incorporated in this phoro-optometer were optically inaccurate, without graduation and without calibration.

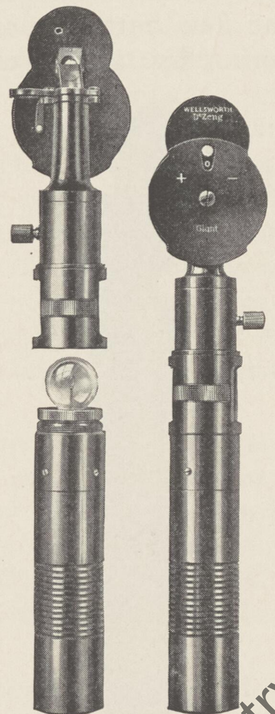

Fig. 8. The Wellsworth DeZeng Giant ophthalmoscope, with its screens for daylight, yellow light and red-free light

DeZeng corrected and improved all these things, accurately graduated his prisms in diopters, supplied ground Maddox rods, mounted the rotary prisms so that they could be used to measure a compound imbalance, covered the lenses with a front and back dial and thus produced his No. 574 model phoro-optometer, which has enjoyed the greatest sale of any instrument on the market.

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Hand in hand with the advancement in phorometry has gone progress in retinoscopy and ophthalmoscopy. DeZeng's contributions to these fields in the form of practical instruments have been unique. He placed at the disposal of the profession the first battery-contained-in-handle instrument, the first anti-reflex type of mirror and finally the

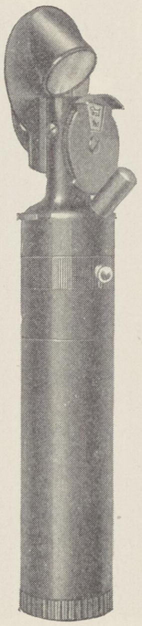

Fig. 9. The Wellsworth DeZeng
Dynamic retinoscope

first flash-light instrument. His numerous improvements upon the ophthalmoscope finally culminated in the Giant ophthalmoscope, permitting examination of the ocular fundus by daylight illumination, as well as by yellow and red-free light.

Then in 1922 Mr. DeZeng[18] completed his "almost perfect phorometer", the Phoroptor, compact and complete.

[18]DeZeng, Henry L. *The Phoroptor.* Published by the author, 1922

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The refractionist of today can work more rapidly and accurately than ever before, since he is but little dependent upon auxiliary or accessory equipment. With it determinations of the anomalies of refraction, accommodation and the extra-ocular muscles of the eyes may be efficiently and exhaustively made. In this instrument DeZeng incorporated the Savage fixed displacing prisms for muscle testing and added batteries of cylindrical lenses (in quarter diopters up to 4.75 D. and in eighth diopters to 1.25D) with a unique and readily used device for setting the axis of the cylinder at any desired position. Rotary prismatic units were reduced to 15Δ, thus allowing wider spacing of scale divisions, consequently securing greater accuracy in the muscular imbalance findings, which is particularly important in the determination of the amount of a vertical imbalance.

And now, the refractionist is presented with the Wellsworth DeZeng Improved Phoroptor, Model 588. The instrument retains all the admirable features of the Phoroptor and has added many new features suggested by the staff of the Wellsworth scientific laboratories working in collaboration with some of the best known authorities in ocular refraction.

Among the improvements over Model 584 which are to be found incorporated in the Wellsworth DeZeng Improved Phoroptor, Model 588, may be mentioned:

1 A total range in power of spherical lenses from +23.88 D. to −24.00 in steps of 0.12 D.

2 A total range in power of cylindrical lenses from 0.12 D. to 9.00 D. in steps of 0.12 D.

3 Lens changes are entirely systematic and there is the nearest approach to a "mobile" lens which is practical.

4 Larger apertures of lenses, thereby avoiding various adjustments previously demanded when small apertures were used.

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5 Double Maddox prism, for use in muscular imbalance tests.

6 Powers of lenses in the rear dial are indicated on the front dial, thereby avoiding confusion and delay in routine refraction.

7 Interpupillary distance more easily and quickly adjusted.

8 Longer handles on the rotary prisms, thus enabling the operator to rotate the prisms with greater ease and increased accuracy of setting.

9 The auxiliary lenses include a pair of -3.00 D. cylinders, a pair of -6.00 D. cylinders, one each of stenopaic slit, $\frac{1}{2}\Delta$ prism, chromatic test, special red glass, and a pair each of cruxite A, cruxite B, cruxite C, $+0.50$ D. $\bigcirc$ -0.50 D. cross cylinder and $+0.25$ D. $\bigcirc$ -0.25 D. cross cylinder.

10 All lenses are calculated on the basis of effective or vertex refraction, thus ensuring findings which are identical with those obtained in the finished ophthalmic lenses furnished the patient.

11 The instrument proper is suspended from above instead of being attached to the upper end of the supporting mechanism as in the older models.

12 Lenses are so computed that regardless of their position in the instrument, their indicated effective power is just 13.75 mm in front of the rear plane of the eyecups.

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CHAPTER II

THE WELLSWORTH DEZENG PHOROPTOR, MODEL 588

THE admitted importance of properly and accurately conducted tests upon the errors of refraction, anomalies of accommodation and imbalances of the extraocular muscles, demands an instrument which is all in-

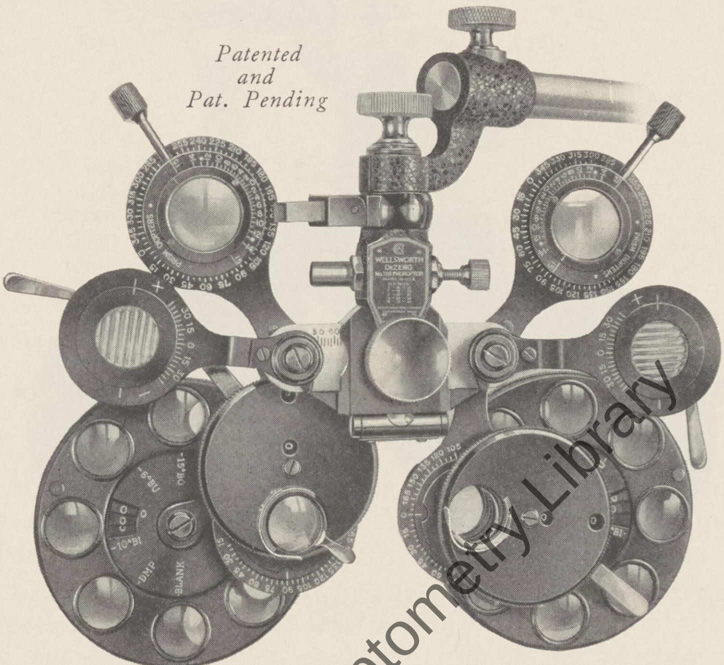

Fig. 10. The Wellsworth DeZeng Improved Phoroptor, Model 588 (Front View)

clusive in its parts, containing all necessary lenses, prisms and accessories, so arranged and placed that the examination may be completed in the least possible time consistent with accurate results and with maximal comfort to both patient and examiner.

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The Wellsworth DeZeng Improved Phoroptor fulfills this demand. The new instrument is suspended from an overhead support, thereby eliminating the likelihood of the patient breathing on the instrument as well as allowing greater freedom in correctly adjusting the instrument to the patient's inter-pupillary distance. The eyecups set in the

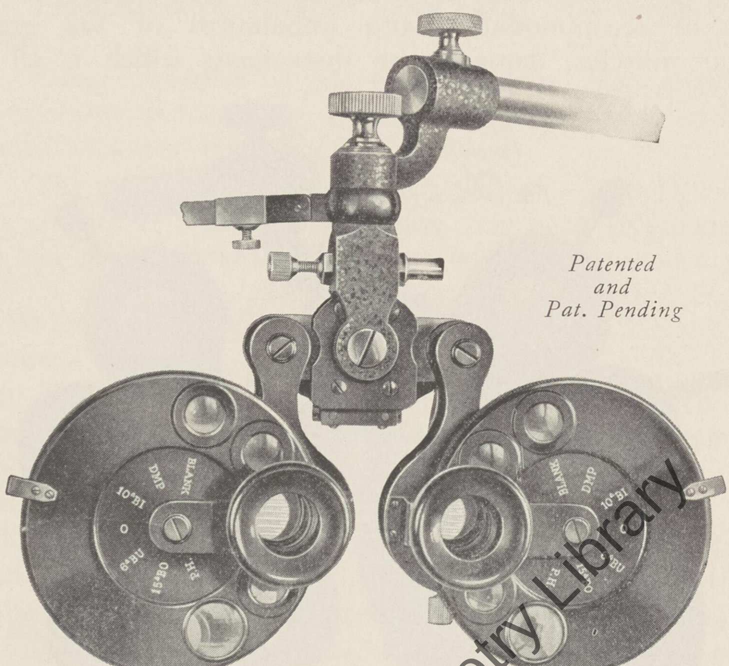

Fig. 11. The Wellsworth DeZeng Improved Phoroptor, Model 588 (Back View)

back of the instrument are of bakelite and can be readily detached. Two sets are supplied with each instrument, so that one pair can be sterilized while the other pair is in use.

MADDOX RODS

Both Maddox multiple rods are made of clear, colorless glass. Either one or both may be made to give colored bands or ribbons of the fixation light by the use of a spectral

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red glass, which is to be found in the accessory case. These Maddox rods are ground and not moulded, thereby affording the person under test a clean-cut ribbon of light. By reason of the mechanical arrangements, these rods may be easily swung out of the way or into position for testing purposes. When the improved Phoroptor leaves the Wellsworth factories the Maddox rod units are so set that the ribbon of light will be seen in a truly vertical position when

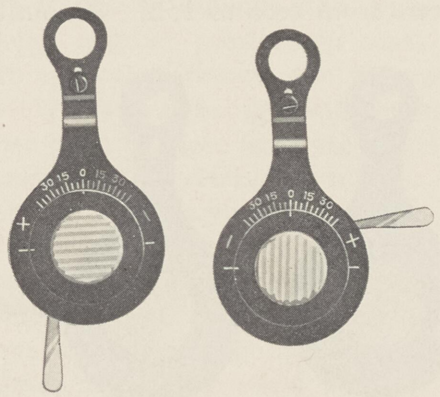

Fig. 12. The Maddox multiple rod units

the axis of the rod is horizontal and when the instrument is leveled, and when the eyes of the patient are properly positioned behind the Phoroptor. After continued use this exact setting may become slightly displaced, in which event correction may be made by altering the position of the small set screw situated near the top of the Maddox rod unit. This set screw acts as a stop, working against an angled surface rigidly attached to the main supporting rods of the instrument.

The cases into which the Maddox rods proper fit are accurately graduated in degrees so that the amount of *plus* or *minus* cyclophoria of each eye may be found. The technic of such examinations is given in a later chapter.

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Each Maddox rod is inserted in a disc which is quickly rotated in its containing case by an attached handle. The operator is also assured of positive vertical or horizontal positioning of the Maddox rods by a suitable mechanical device, thus obviating the necessity of actual visual adjustment.

ROTARY PRISMS

The two rotary prismatic units are graduated accurately in prism diopters from zero to 15Δ. Amounts of muscular

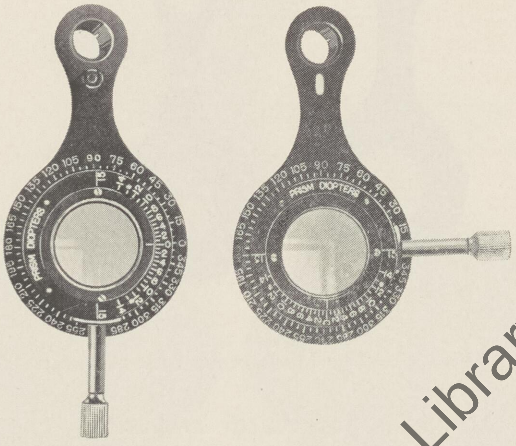

Fig. 13. The double rotary prism units

imbalances (or correcting prisms) as low as 0.5Δ are easily read. This is of especial importance in vertical imbalances. Since it is sometimes necessary to have prisms as high as 30Δ base out in value before each eye, a supplementary fixed prism of 15Δ base out is placed in the dial of the lens batteries which also carries the 10Δ, base in, and 6Δ, base up, prisms. This 15Δ prism is, therefore, always base out when placed before the patient's eye. An auxiliary 10Δ, base in, permits of a total of 25Δ, base in, before either eye. An additional 6Δ, base up, in conjunction with the rotary prism

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permits of the measurement of vertical imbalances as high as 21Δ. (Cases of large vertical imbalance are not frequent, but the literature cites several.)

The cases carrying the prisms are also graduated accurately into degrees, so that the operator may not only determine the amounts of muscular imbalance through the use of prisms base up, down, in or out, as the case may be, but, having determined these imbalances, he may place the resultant prism of proper amount and with its base-apex line in the proper angular position in cases of compound imbalances. In optical parlance, the base-apex line of a prism is commonly taken as being analogous to the axis of a cylinder, because both of these lines are correlated with the directions or meridians of refractive power. Obviously it makes no difference how a cylindrical lens is inserted in a trial frame as long as the axis line passes through the center of the cell or opening, thus avoiding any possibility of prismatic effect, and each end of the cylinder axis marking is read at the same numerical angular position. But it does make all the difference in the world whether, for example, the base of a prism is up or down. In one case (base up) the base-apex line is from 90° to 270° (using the full 360° circle), while in the other instance (base down) it runs from 270° to 90°. One would therefore specify a prism base up as being a prism, base-apex line 90°, and a corresponding prism base down as being a prism, base-apex line 270°. Proceeding further and remembering the manner in which the standard trial frame is graduated (*i. e.* counter-clock wise when held in front of the observer's face), we see that, for the *right* eye, base in is base-apex line 0° and base out is base-apex line 180°, while for the *left* eye, base in is base-apex line 180° and base out is base-apex line 0°. For example, then, if the rotary prism is turned before the right eye so as to indicate 2Δ base in, or base-apex line 0°, hence correcting an exophoria of that amount, and if the rotary

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prism before the right eye is turned subsequently so as to indicate 1Δ base up, or base-apex line 90°, hence correcting a left hyperphoria of 1Δ, we have as a resultant O. D. 2Δ base in ⊃ 1Δ base up, or 2Δ base-apex 0° ⊃ 1Δ base-apex 90°. By principles of geometry and trigonometry, or by reference to one of the tables to be found in the appendix of this volume, we find that this is equivalent to O. D. 2.23Δ base-apex at 30°. The rotary prism, therefore, before the right eye should be set at 2.25Δ and rotated until the indicating mark upon the rotary prism is at 30°. The compound imbalance will then be fully corrected, and tests can thus be made to see if such a correction, if ordered, will be satisfactory. As another example, we will assume the following data: O.S. 2Δ, base in, with 1.5Δ base down. The base-apex lines are, therefore, 180° and 270°. The resultant prism will be O.S. 2.5Δ base-apex at 231°, which may be conveniently written 2.50Δ, B. A. 231°. Such information is useful in the examining room and also when writing a prescription in which both a vertical and horizontal prism are incorporated in one lens.

Since the rotary prism units are composed of two 7.5Δ and since the inner surfaces of these prisms may become soiled or cloudy, it is important to clean occasionally both inner as well as outer surfaces. Many users of high-grade instruments fail to appreciate the importance of keeping all optical parts clean, forgetting that "cleanliness is next to Godliness" and a requisite to all successful refraction. One of the improvements in the construction of the double rotary prism units in the new Phoroptor lies in the provision for quickly removing and cleaning the prisms. The rotary unit is so arranged as to consist of a two-part prism cell, which permits of the removal of one of the prisms by raising the two retaining screws and taking out the prisms fixed in its cell. The screws are purposely placed out of alignment, thereby preventing improper return of the prism to the

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unit. This novel feature constitutes an important addition, for hitherto inaccessible parts are now readily reached, and the prisms may be cleaned without any possibility of disturbing the assembly or impairing the accuracy of their optical performance.

Another special feature of the improved Phoroptor lies in the adjustment for the proper position of the rotary prism units. When the instrument leaves the factory the exact

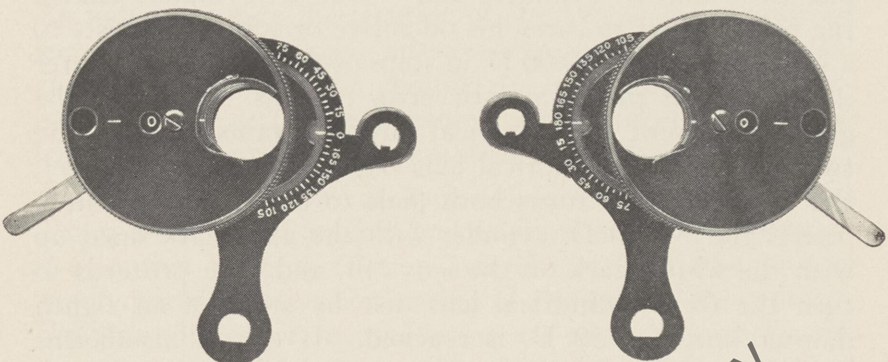

Fig. 14. The cylindrical batteries and additional lens clip

positions of the rotary prism units are set and fixed. Due to wear and continued use, it may happen that the units do not rest in exact position before the sight-openings when they are swung into position. An adjustment to insure this accuracy of position has been provided in the Phoroptor by means of an adjustable set screw in the neck of the rotary prism units. This set screw rests against an angled surface. By movement of the screw, up or down as the case may demand, the positions of the rotary prisms before the sight-openings may be changed and proper alignment secured.

BATTERIES OF CYLINDRICAL LENSES

The cylindrical lenses used in the improved Phoroptor are minus (concave) in character.

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The front dial of each unit carries cylinders having values of −0.12, −0.25, −0.37 and −0.50 respectively and an open sighthole.

The second dial of the cylindrical unit carries cylinders having powers of −0.63, −1.25, −1.88 and −2.50 D. respectively, and an open sighthole. The range of the cylindrical lens power incorporated in each unit is from 0.12 D. to 3.00 D., in intervals of an eighth of a diopter. The auxiliary pair of −3.00 D. cylinders and −6.00 D. cylinders enable the refractionist to carry his objective or subjective tests to a value as high as −9.00 D. in steps of an eighth of a diopter if desired. If the astigmatic error exceeds −3.00 D. (the greatest amount of cylindrical power obtainable from the two dials of the cylindrical lens battery of the Phoroptor), the examiner then turns both dials to the "zero" (0) stop, inserts the −3.00 D. cylinder with the axis mark lined up with the white mark on the lens cell, and then proceeds to turn the front cylindrical lens disc by steps of an eighth diopter until −3.50 D. is reached. If this is insufficient the operator then turns simultaneously both front and back cylindrical lens discs, thereby removing the −0.50 D. cyl. and inserting the −0.63 D. cyl., thus giving a total value of −3.63 D. cyl. Greater cylindrical lens power may be obtained by rotating the cylindrical dials temporally, in steps 0.12 up to 6.00. If higher cylindrical power is required remove the −3.00 D. cyl. from lens cell and insert the −6.00 D. cyl. from the accessories which enables a total of −9.00 cylinder being obtained.[1] The Wellsworth DeZeng Improved Phoroptor is the only instrument in which such procedures, not infrequently demanded in routine refraction, are possible.

All cylindrical lenses are accurately mounted with their axes radially placed, thus insuring exactly the same position

[1] The indicated powers of lenses in this Phoroptor, are calculated on an additive basis, referring to the power of the lens when used in combination and not to its actual power if removed from the battery.

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of axis as each cylindrical lens is turned into position before the sight-opening. Stop rings of precise construction with internal locking members are used so as to secure accurate positioning of each lens and to insure smooth rotation of the dials in which they are placed.

The setting of the axis of any cylinder at any desired position before the eye is accomplished by swinging the entire cylindrical unit about the line of sight passing through the center of the sight-opening and serving as a pivotal axis. An index registers the position of the axis of the cylindrical lens on the degree scale engraved on the supporting mechanism. The circle is completely graduated, thus permitting of the setting and reading of the axis of a cylindrical lens in two positions at opposite ends of a diameter.

A handle is attached to each cylindrical lens unit so that it may be set very quickly and easily at any degree desired. A smoothly working friction attachment holds the unit at any required position for setting of the axis of the cylinder, while the dials carrying the lenses are rotated to obtain the desired cylindrical power. Thus friction or resistance to turning of the dials can be adjusted to suit the touch of the operator. This is a very important and desirable adjustment, since the requirements with reference to either "looseness" or "tightness" of the moving parts of optical instruments varies greatly with practitioners. When the inst-ument leaves the factory the adjustment for friction is about medium. If this seems to be too stiff, it may be changed very quickly by a slight loosening of the three small screws at the back of the cylindrical lens battery, or if too loose, by simply tightening these same screws.

Furthermore, the handle, which serves as the medium for swinging the unit about the sight-opening so that any desired position of axis may be secured, forms a convenient rest for the thumb and the second finger of the hand while the dials are being turned by the index finger. Thus the

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operator may make changes easily and rapidly in both cylindrical lenses and positions of axis with but slight movements of the fingers and of the arm.

BATTERIES OF SPHERICAL LENSES AND AUXILIARY PRISMS

The front or first dial of the battery of spherical lenses carries seven lenses, as follows: +0.12, +0.25, +0.37, +0.50, +0.62, +0.75, +0.88 D. and, in addition, one open sighthole.

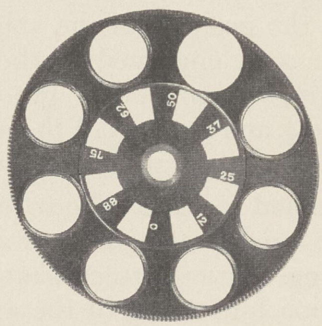

Fig. 15. The front spherical dial of the Phoroptor

The second dial, immediately behind the rotatable front dial, contains convex spherical lenses in units of a diopter from +1.00 to +7.00 D. inclusive, as well as an open sighthole.

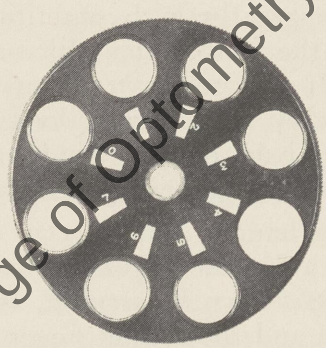

Fig. 16. The second spherical lens dial of the Phoroptor

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The third dial, immediately behind the second dial, contains the following supplementary lenses: +16.00, +8.00, −8.00, −16.00 and −24.00 D. respectively. The convex lenses are separated or divided off from the concave lenses by an open sighthole.

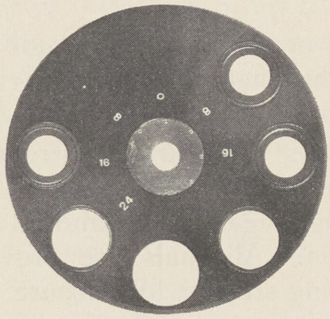

Fig. 17. The third spherical lens dial of the Phoroptor

The fourth or back dial, closest to the patient's face, contains a pinhole disc; a 15Δ fixed base out; a 6Δ fixed base up; an open sight aperture; a 10Δ fixed base in; a double Maddox prism fixed displacement vertical and occlusion

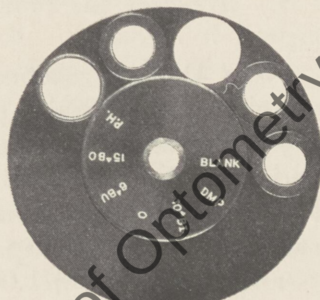

Fig. 18. The back dial of the Phoroptor

blank. The uses of these various prisms and the methods of employing them are set forth in subsequent portions of this treatise.

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The correct position for a lens is recognized by all authorities as being 13.75 mm from the cornea. The new Phoroptor is so constructed that when the ocular plane of the eyecups is tangent to the cornea, the prescription obtained will be interpreted as a lens placed at 13.75 mm from the eye.

Another feature of the new Phoroptor is that it can be adjusted so that the line of vision is at right angles to the surfaces of the lens.

The spherical lens dials are constructed with knurled edges to facilitate rotation. The dials are rotated by lightly pressing the forefinger against the knurled edges and turning in desired direction. All dials are provided with three-point, positive spring stops, which insure correct alignment and positive positionings of the lenses before the sight-openings.

Convex lenses:—The operation of the spherical lens batteries is simplicity itself. The front dial carries convex spherical lenses in eighth diopters to +0.88 D. S. Each change in the *temporal* direction *increases* the *convex* power by 0.12 D. S. and each change of lenses *nasally* (starting with the +0.88 D. S.) *decreases* the *convex* power by 0.12 D. S.

When a value of +0.88 D. S. is reached and +1.00 D.S. is desired (all dials having been initially placed so that the sight-openings only are in front of one eye, the other eye having been occluded), the finger should be placed upon both the front dial and second dial immediately behind it and turned temporally to the next stop. This turns out the +0.88 D. S. lens and inserts the +1.00 D. S. before the eye. Increase in convex spherical power can now be obtained, by steps of +0.12 D. S. at a time if desired, by turning the front dial only.

When +1.88 D. S. is reached, the finger should be placed on both the first dial and the second dial immediately be-

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hind it and these should be turned temporally to the next stop. This turns out the +1.88 D. S. value and places the +2.00 D. S. before the eye. By proceeding in the same manner, the +3.00, +4.00, +5.00, +6.00 and +7.00 may be placed, as desired, before the eye under examination, with intermediate steps of +0.12 D. S. up to 7.88 D. S. When the contents of the front dial and second dial have been exhausted, the +8.00 D. S. may be turned into position before the eye by grasping the first, second and third dials with forefinger and thumb and turning temporally, which will cause open apertures on first and second dials to fall in position and a +8.00 D. S. on the third dial, and the lens power may be increased to +8.88 D. S. by turning the front dial temporally step by step.

Without going into further detail, it is obvious from a study of the contents of the front dial and two intermediate dials that a total power of +23.88 D. may be obtained by continuing the rotations in the same manner and that reductions may be made in this power by steps as small as 0.12 D. S. No such range and rapid method of change of convex (plus) spherical lenses exists in any instrument previously devised and built.

Furthermore, the divisions of lenticular power as provided in the various dials of the improved Phoroptor gives an elasticity in the use of lenses previously unknown. By the use of the front dial the steps in refractive work (either objective or subjective) may be made as small as 0.12 D. S. By means of the dial immediately behind the front dial, the changes may be made in steps of 1.00 D. S. This is of great assistance as a time saving device, especially in changing from the distance to the reading corrections or vice versa. Likewise, in retinoscopic work, the examiner can set the front dial at +0.50 D. S. and the dial behind it at +1.00 D. S. (making a total of +1.50 D. S. for a working distance of 66.6 cm. or 26 inches), and if he finds a sluggish

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"with" motion using the plano mirror, he can make his initial lens changes at the rate of +1.00 D. S. increase by turning the second dial temporally a step at a time. If, perchance, he uses a working distance of one meter, then a +1.00 D. S. in the second dial allows for his working distance, and he can proceed to "rough out" his work by changes of 1.00 D. S. at a time.

Concave lenses:—When concave (minus) spherical lenses are needed, as in the correction of myopia, the initial procedure is to set all dials with open sights before the eye under examination. Then turn *nasally* the first, second and third dials one step. This will place before the eye the following lenses:—(1) In the first dial, +0.88 D. S. (2) in the second dial +7.00 D. S. and (3) in the third dial −8.00 D. S. The sum of these lenses is −0.12 D. S. By turning the first dial *nasally* one step at a time, the convex (plus) power is reduced by 0.12 D. S. at each step or the *concave* power is increased by 0.12 D. S. For example, if the first dial reads +0.25 D. S. the second dial +7.00 D. S. and the third dial −8.00 D. S. the correction before the eye is −0.75 D. S.

If the myopia is greater than 1.00 D. S. then rotate the first dial and the second dial *nasally* one step. This places the +0.88 D. S. before the eye in the first dial and simultaneously inserts the +6.00 D. S. in the second dial. The −8.00 D. S. in the third dial, it is to be remembered, is not touched. The equivalent value before the eye is now −1.12 D. S. (*i. e.* −8.00 D. S. + 6.88 D. S. = −1.12 D. S.). Further changes of an eighth of a diopter may then be made by rotating the first dial nasally a step at a time.

When the corrective value has reached −2.00 D. S. (*i. e.* −8.00 D. S. in third dial and + 6.00 D. S. in second dial), the next change of increased minus correction may be made by turning the first dial and second dial nasally one step, giving a correction of −2.12 D. S. By proceeding in the same manner, the +5.00, +4.00, +3.00, +2.00, +1.00

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D. S. and zero, may be placed as needed, in front of the −8.00 D. S. in the third dial, with intermediate steps of −0.12 D. S.

When the contents of the first and second dials have been exhausted (−8.00 D. S. in third dial, and first and second dials reading zero) then turn the first dial and the second and third dials *nasally* one step. This then inserts before the eye the −16.00 D. S. in the third dial, the +7.00 D. S. in the second dial and +0.88 D. S. in the first dial giving a total of −8.12 D. S. Without going into further detail, it becomes obvious, from a study of the contents of the first, second and third dials, that a total power of −24.00 D. S. may be obtained and that increases from zero to this power (−24.00 D. S.) may be obtained in steps as low as −0.12 D. S.

In using the batteries of spherical lenses in the Phoroptor, the operator will be greatly assisted if he will remember this rule:

When all dials are set at zero, any rotation of the first, second and third dials temporally will increase the convex (plus) correction, as called for in hyperopia: any rotation of these three dials nasally will increase the concave (minus) correction, as called for in myopia.

The following summary may be of value to those who are not accustomed to the use of previous models of Phoroptors or phoro-optometers:

1 Any rotation of the first dial temporally increases the convex lens power before the eye by 0.12 D. S.; conversely, any rotation of this dial nasally decreases the convex lens power by 0.12 D. S.

2 Any rotation of the second dial (carrying from +1.00 D. S. to +7.00 D. S. inclusive) temporally increases the convex lens power before the eye by 1.00 D. S; conversely, any rotation of this dial nasally decreases the convex lens power by +1.00 D. S.

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3 Rotations of the third dial temporally increases the convex lens power by steps of +8.00 D. S. ; conversely any rotation of the third dial nasally decreases the convex power by steps of 8 D. S. as in passing from +16.00 D. S. to +8.00 D. S., from +8.00 D. S. to 0, from 0 to −8.00 D. S. and so forth.

4 In cases of hyperopia, one may overcorrect the error in all meridians and then reduce the convex lens power by rotation of dials nasally. For example, the first dial may be set at 0.88 D. S. and the second dial at +2.00 D. S. Then rotating the front dial nasally will reduce the convex spherical power 0.12 D. S. at each step, and so on.

5 In cases of myopia, the lowest concave lens value may be obtained by turning the first dial to +0.88 D. S., the second dial to +7.00 D. S. and the third dial to −8.00 D. S. If all dials had been initially set at zero, one step nasally of all three discs would have accomplished this result. Concave lens power is then increased by turning any desired disc (depending upon the rate of change of power desired) nasally.

ACCESSORIES

The accessories supplied as standard equipment to be used in the supplementary lens cell are:

1 pair	−3.00 D. Cyl.
1 pair	−6.00 D. Cyl.
1 pair	Chromatic test (cobalt blue)
1 pair	Red glass
1 pair	Cruxite A
1 pair	Cruxite B
1 pair	Cruxite C
1 pair	0.25 D. cross cylinders
1 pair	0.50 D. cross cylinders
1 only	½Δ prism
1 only	Stenopaic slit

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The great advantage in the procedures which have been described in the use and manipulation of the convex and

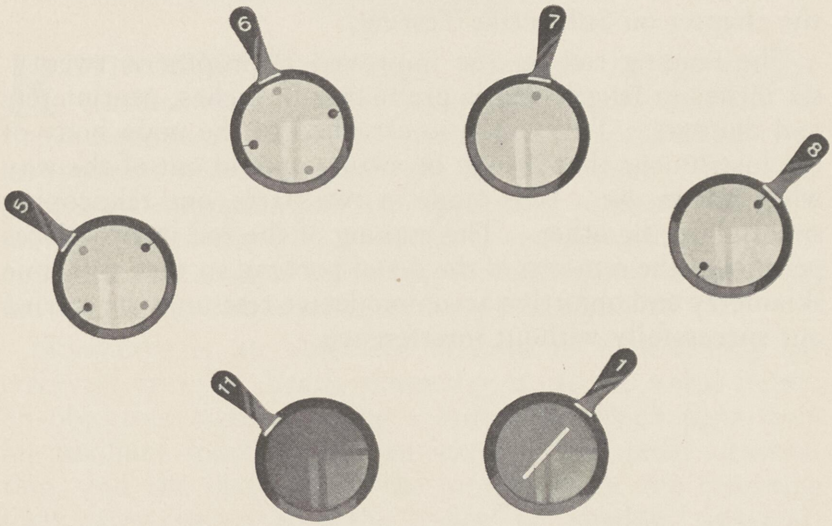

Fig. 19. Some of the accessories for use in the front lens clip

concave lenses ought to be commented upon, for this gives the ideal method in the so-called "fogging" system. For

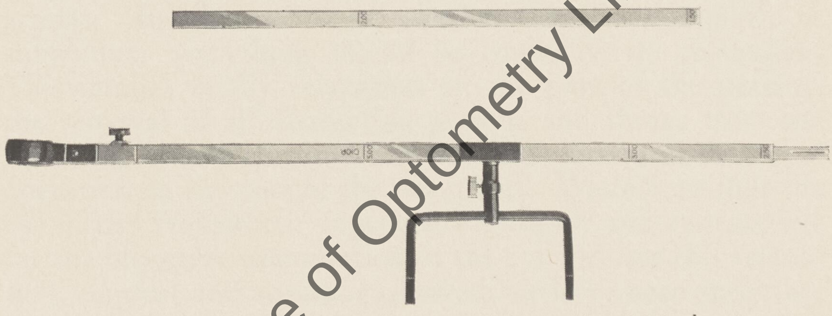

Fig. 20. The two-piece reading rod: the main portion 16 inches long and the second portion (removable) 10 inches long

the eye under test may always be kept under maximal convex lens power as it is reduced step by step by proper manip-

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ulation of the various dials of lenses. Or again, in cases of myopia, it may be kept under the minimal amount of concave lens. Some of those points will be discussed further in the chapter on Subjective Testing.

The reading rod on the improved Phoroptor is twenty-six inches in length and is graduated in inches, centimeters and diopters. This rod is so attached to the main body of the instrument that it may be swung up and out of the way when not in use. It is made in two parts, one telescoping snugly into the other. The making of the rod in two pieces permits of the removal of the distal portion, so that dynamic skiametry and objective accommodative tests may be carried out successfully without interference.

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CHAPTER III

STATIC SKIAMETRY AND THE IMPROVED PHOROPTOR

RETINOSCOPY, skiascopy, skiametry or the shadow test has been for fifty years an objective method for the measurement of ocular refraction by means of the real or apparent movements of light on the fundus. The laws governing conjugate foci are applicable to these objective methods since the eye, although a complicated system, is equivalent to a single refracting surface separating media of air and water with a posterior length of about 20 cm.

Skiametry is an objective method of neutralizing the errors of an eye. Static skiametry is, as the words imply, an objective method (using a mirror by which light from an auxiliary source is thrown into the eye under observation, and the direction of the movement of the returning light, often referred to as the "reflex" or "shadow", is noted) for determining the refractive condition of an eye at rest. The functions of accommodation and convergence are, therefore, allayed in so far as such is possible under certain modes of procedures to be presented in the succeeding paragraphs. In all static tests, whether these be skiametric or subjective, everything should be conducive to relaxation. This implies bodily relaxation on the part of the patient, the removal of all distracting persons and things from the refracting room, and last but not least ease and surety of operation on the part of the examiner. We believe that the use of the Wellsworth improved Phoroptor and instruments for the objective examination of the eye induces this relaxation, comfort and accuracy of which we have been speaking.

FIXATION DEFINITE BUT PASSIVE

Definite but passive fixation is necessary in order to induce ciliary relaxation in tests conducted without the use of

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a cycloplegic. When the fixation is not definite and passive the static skiascopic findings are often uncertain and inaccurate, because indefinite fixation means changes in the act of accommodation on the part of the person under examination; consequently an inexact spherical or cylindrical finding may result.

SOME THINGS TO BE IGNORED OR AVOIDED

In the practice of retinoscopy there are some things to be ignored or avoided. These may be briefly stated:

1 There may be a retinal vessel or a remnant of a hyaloid artery or even the nerve head which will be seen when the light is thrown into the eye: these must be ignored as they form no part of the test.

2 With oblique illumination, such as would be obtained by working at a considerable angle or with the patient's eye fixing a point considerably out of line with the observer's line of vision, incorrect findings will often result. Hence, the line of the patient's fixation and the line of the operator's observation should be as nearly as possible identical.

3 Reflections of light from the neutralizing lens or lenses or even from the cornea may occur when these are obliquely situated with respect to the line of observation and often the retinal reflexes are obscured or dimmed. The remedy is obvious.

4 The catoptric images—*i. e.* the images of the light-source formed by reflection at the corneal surface, and so forth—cannot be avoided or obviated but the operator must learn to ignore them.

5 The small dark central area seen upon the cornea is due to the image of the sighthole, but this forms no part of the true skiametric shadow and should be ignored.

The use of a small retinoscopic mirror with small aperture minimizes some of these sources of error.

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SUMMARY OF IMPORTANT POINTS IN SKIASCOPY

A well-known writer on skiascopy gives the following summary of important points in skiametry.

I. *Apparatus.* "1 A reasonably darkened room; the darker the room the easier for the beginner. The writer recommends a condition of illumination in which the numbers on the handles of the lenses of the trial case or the values indicated on the phoroptor can be readily seen. Do not fumble around in your skiametric work. The darker the remainder of the room, especially that part into which the patient is looking or fixating, the better."

"2 Do not let the patient look anywhere and everywhere he chooses. For in so doing he will vary his direction of gaze and if not under a complete cycloplegic will cause the skiametric findings to vary on account of accommodative changes."

"3 Have the patient seated comfortably and find some comfortable and graceful manner for the execution of your skiascopic refraction. An adjustable stool is par excellence for this purpose."

"4 Employ a modern self-luminous retinoscope. Or if you use the so-called 'oculist lamp,' have the source of illumination well screened and on an easily adjusted bracket. An iris diaphragm in an asbestos chimney and a telescopic bracket may be employed."

5 Use a small mirror with a small aperture or better still a transparent reflector, as fitted to the new Giant retinoscope. It is desirable that the examiner learn to use either eye in his work.

The Wellsworth professional refracting chair assures comfort to the patient; the Wellsworth adjustable stool affords the examiner a means of proper position for a skiascopic examination; the WELLSWORTH IMPROVED PHOROPTOR (No. 588), when properly adjusted before the

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patient's face, prevents changing of gaze and wandering of fixation; the Wellsworth DeZeng Giant retinoscope No. 276 embodies all of the highest scientific requirements for exact retinoscopy.

II *Procedure and points in routine practice:* "1 Refract the eye in the line of sight (vision) and in the visual zone."

"2 Using a plane mirror, the observation point being one meter, the retinoscopic reflexes or shadows will move "with" the directions of movement of the mirror in emmetropia, hyperopia and myopia of less than one diopter."

"3 An observational distance of 26 inches is, all things considered, a most desirable one we believe. For this distance a −1.50 D. S. must be added algebraically to the total lens quantity before an eye in order to find the true static skiametric correction."

"4 In estimating a spherical error, either the method of finding the reversal point or the bringing of the reversal point to any specified distance from the eye under observation may be adopted. It is well to use both methods."

"5 In astigmatic conditions, two reversal points will always exist. This means that a cylindrical correction is demanded. The amount of the cylindrical correction may be determined by (1) finding the location of the two principal meridians and converting each distance into diopters, the difference then representing the amount of astigmatism, (2) neutralizing each meridian with spheres at a fixed observation distance, of (3) using spheres and cylinders and obtaining a neutral shadow at a specified distance of observation."

Fixation at a point twenty or more feet away may be taken as representing a practical fixation at infinity. (Theoretically 0.16 D. of accommodation is used by the patient for fixation at 20 feet or 6 meters.) The refractionist, therefore,

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under such a procedure, has to make an "allowance" only for his own "working" distance. Various working distances and allowances are:

Working Distance		*Allowance*
1 meter,	40 inches	1.00 D.
80 cm.,	32 inches	1.25 D.
66 cm.,	26 inches	1.50 D.
56 cm.,	22 inches	1.75 D.
50 cm.,	20 inches	2.00 D.

THE MACULAR REFLECTOSCOPE

We have pointed out that definite but passive fixation is required in all static tests, other than those in which a cycloplegic is used, in order to induce and to obtain the greatest ciliary relaxation possible in such procedures. Such passive fixation may be secured by the definite fixation of a large letter at a distance of 20 feet or more. However, with such a fixation and without the use of cycloplegics, the skiascopist, in applying his static objective methods, falls into error by reason of the fact that his refractive determinations are commonly made at an angle with reference to the visual axis.

Therefore, one of the chief sources of error and discrepancy in retinoscopic work lies in the fact that most skiascopists do not determine the refractive error along the visual axis and with that portion of the retina which is conjugate to the point passively fixed. When making the subjective visual acuity tests (Snellen charts) the person under examination views or fixes each of the letters in turn: an image of these letters, one at a time, is normally formed on the fovea centralis. In the ordinary method of practicing skiametry an image of the light source used is produced upon the subject's retina at a point which is several degrees from the fovea centralis. We may at best, under average conditions, be conducting the examination along the optic axis. If, as

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is quite commonly done, the patient's gaze with regard to his right eye is directed over the operator's right shoulder and over his left shoulder for the left eye, the image of the light from the operator's mirror may fall at or near the optic disc, as is evidenced by the character of the reflexes obtained.

Optic discs are unlike as to contour, peripheral elevation or depression and so forth. Also, one has no right to assume a uniformly curved or spherical retinal surface. For these and other reasons, objective findings may vary considerably depending upon the portion of the fundus which forms the conjugate point to the observer's own fovea. The knowledge of the fact that one millimeter change in axial depth of an eye corresponds practically to a change of three diopters in refractive power indicates the marked effects which slight differences in level between two retinal points made conjugate, in turn, to the observer's nodal point may produce. The vital point is that skiascopic findings are not ordinarily made along the visual axis and hence many irregularities and disagreements between objective and subjective findings arise because of lack of proper scientific precautions in the conditions under which these tests are carried out.[19]

When, therefore, the skiascopic examination is made at an angle with the visual axis there arises, in conformity with the laws governing the refractive power of a lens tilted at an angle, an error in the spherical element and the introduction of a false astigmatic correction.

The undesirable condition of affairs is illustrated in Fig. 21. To test these statements out, the reader is requested to take a No. 817 DeZeng schematic eye and self-luminous retinoscope and, setting the eye for about 1.5 D. of myopia, take a position so that the observing eye is about 26 inches away and directly in line with that which corresponds to

[19]Sheard, Charles. *American Journal of Physiological Optics*, Vol. 3, p. 348, 1922. Also, *Ocular Accommodation*, pp. 18-21, American Optometric Association Course No. 14, 1920.

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the visual axis of the eye (*i. e.* the optic axis of the schematic eye) and observe the retinoscopic shadow. A neutral shadow should be obtained but, if the distance of the observer or the setting of the schematic eye is slightly inaccurate, the observer should alter his distance from the eye

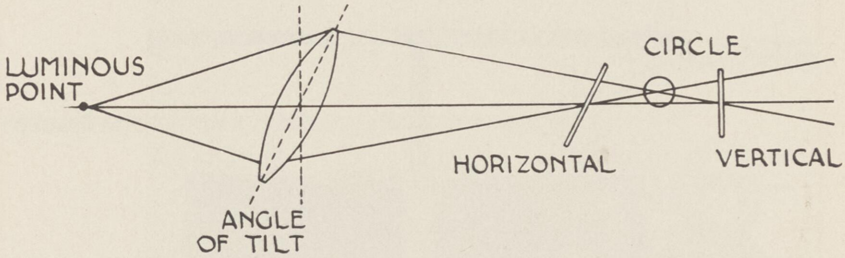

Fig. 21. Diagram showing the false astigmatism caused by oblique examination in static skiametry

until a neutral shadow is obtained. Let the observer maintain this position and then turn the schematic eye (or better still, let an assistant do it) some 10 or more degrees to the right or left. Or let the observer move his head in the same horizontal plane to the right or left. A condition of astigmatism, with axis vertical, will be found to exist. Resuming the original position along the optic axis of the schematic eye will eliminate this astigmatism due to oblique refraction. If the observer modify this experiment by raising or lowering the head, hence changing the angle of observation in the vertical plane, he will find that a false astigmia, axis 180°, has been introduced.

The macular reflectoscope which can be supplied with the improved Phoroptor eliminates these difficulties. The following diagram (Fig. 22) shows the essentials of the device. The macular reflectoscope (Fig. 23) is represented at D and consists of two parallel, plane mirrors, L and N, so placed before the eye of the person being examined as to enable a well illuminated 100 or 200 foot letter (E in the figure) to be seen or at least fixed upon by the eye in its primary posi-

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tion by reason of the two reflections of light from the surfaces of the mirrors L and N placed at an angle of about forty-five (45) degrees with the line of sight. The double mirror device (of which one mirror is slightly larger so that its frame will

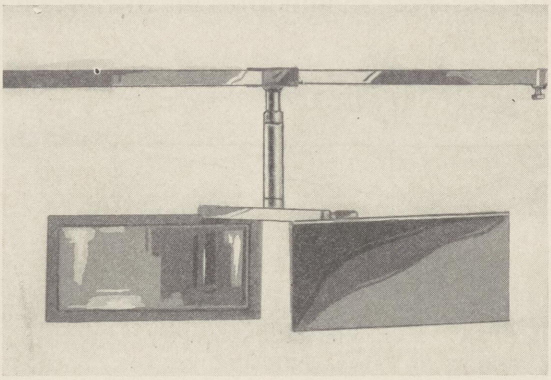

Fig. 22. The macular reflectoscope

not be visible in the second mirror) causes a lateral shifting of the letter or letters viewed: a single ray of light from the illuminated letter E to the macula M is shown as E, L, N, M. The operator, O, with retinoscope at R, may then proceed

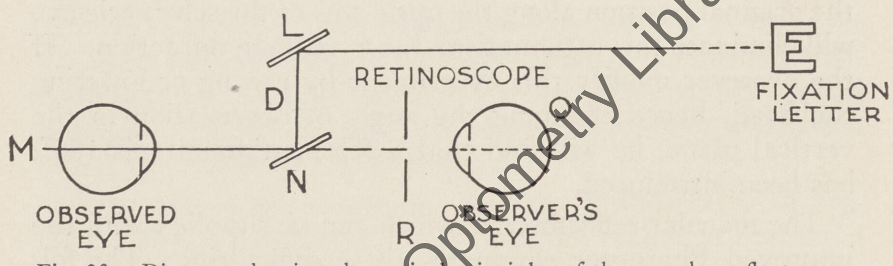

Fig. 23. Diagram showing the optical principles of the macular reflectoscope

with the skiametric refraction of the eye in a direction very closely approximating the visual axis of the person under examination.

The macular reflectoscope permits an accuracy in static skiametry that warrants its use in objective determinations

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of the refractive errors both with and without cycloplegics. Through its use the possibility of incorrect findings will be greatly reduced.

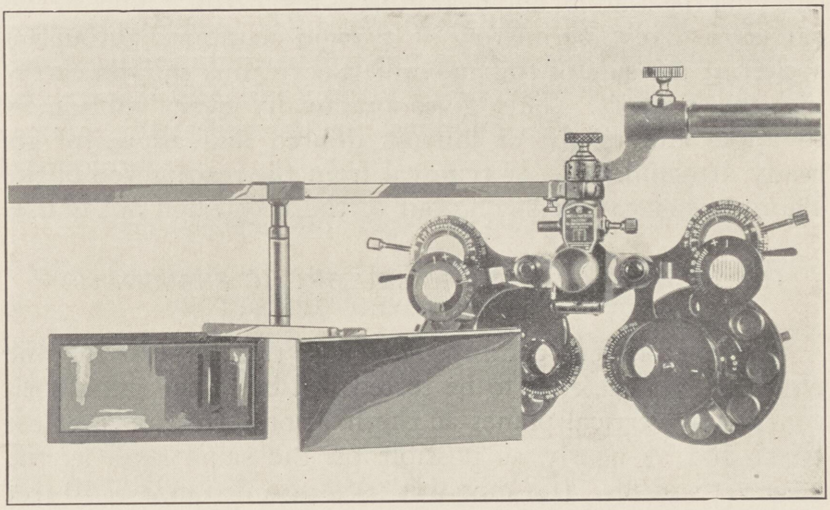

Fig. 24. Showing the macular reflectoscope ready for use on the Phoroptor

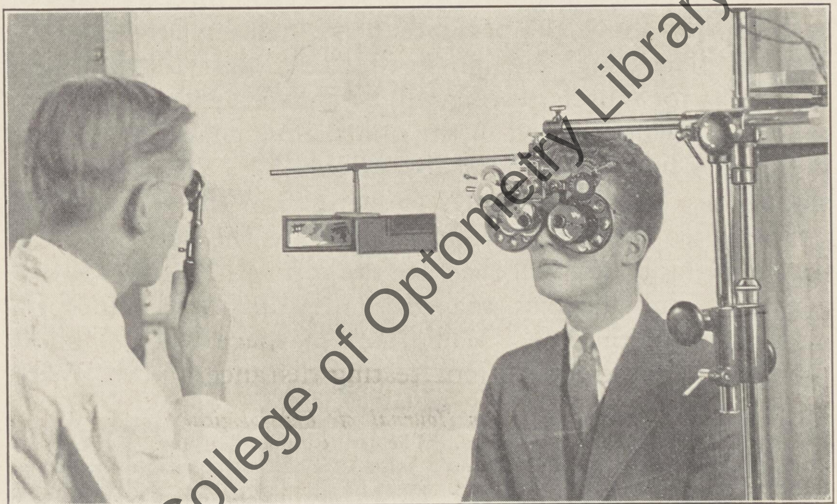

Fig. 25. Showing the macular reflectoscope in actual use on the Phoroptor.

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The present reflectoscope, as designed by Sheard[20], is attached to a special sleeve which may be moved along the rod ordinarily attached to the Phoroptor and employed for carrying the reading and near muscle-test cards. This sleeve carries a screw permitting of its rigid clamping; through a socket at the side of this movable sleeve runs the rod carrying the mirrors. This gives practically every motion as to angle and height of mirrors desired and allows of its ready attachment to or removal from the reading rod of the Phoroptor or can be swung out of the way when not in use.

THE ROUTINE OF A STATIC SKIAMETRIC EXAMINATION USING THE IMPROVED PHOROPTOR

Seat the subject comfortably, adjusting the ophthalmic chair so that the eyes to be tested will be in the same horizontal and vertical planes as the fixation letters on the test chart and as nearly as possible on the same level as the observer's head. If a mirror is used at a distance of 10 feet instead of a direct-reading test chart placed at 20 feet, it is best to have the chart with reversed letters directly back of and slightly above the patient's head, making sure that the chart is placed high enough so that the lower test-line and spot light for muscle testing will be above the head of a very tall person when seated in the ophthalmic chair, which has previously been adjusted as low as possible. The test chart should also be tilted slightly forward from the top and the mirror tilted from the bottom and toward the patient. The person being tested will then see the top and bottom rows of letters on the chart, as imaged in the mirror, at a uniform distance from the eye. When lack of space will not allow the use of the direct, 20-foot testing distance and a mirror

[20]Sheard, Charles. *American Journal of Physiological Optics*, Vol. 3, p. 348, 1922, and earlier writings. The principle underlying the reflectoscope is claimed by various persons. John C. Eberhardt probably designed and used the first device of this type. Sheard first adapted it to the Phoroptor. Armbruster, Herbin and others have written about its successful use and its advantages.

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has to be used, it is best to place the chair so that the distance from the face of the patient when seated in the chair will be nine feet to the front of the mirror, and the distance from the mirror to the test-chart eleven feet, thus making a 20-foot fixation distance. This arrangement will afford the examiner sufficient space or room back of the chair so that he may pass behind the patient if he needs to or, again, for angling the chair when necessary in ophthalmoscopic examinations.

I. STATIC SKIASCOPIC TESTS WITH CYCLOPLEGICS

With the patient properly seated in the ophthalmic chair, swing the Phoroptor into position before the eyes to be tested. See that all dials are set at the zero position, hence leaving all sight-apertures in all dials open and in front of the patient's eyes. (It is a saver of time, as well as an aid in avoiding error and confusion, if the operator sees to it that his Phoroptor is left, after the completion of any examination, in such shape as to be ready for the next patient.) Adjust the Phoroptor proper to the correct horizontal and vertical position with the ratchet and pinion adjustments on the supporting uprights. Adjustment by means of a spirit level enables the operator to get correct horizontalism of the Phoroptor. After first taking the interpupillary distance with the ordinary millimeter scale, adjust the instrument to the required interpupillary distance (abbreviated as P.D.). See that the eyes are within the eyecups. Turn the opaque disc or blinder on the rear dial into position in front of the eye not under test. Take up the customary retinoscopic working distance and proceed to the retinoscopic examination. A distance of 26 inches (66.6 cm.) is recommended for the reason that the examiner may, at this distance from the Phoroptor, readily make all lenticular changes without altering his position and without the necessity of breaking into the continuity of his observations. This routine procedure is a great saver of time to the operator, as

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well as adding to his comfort and the accuracy of his work.

Turn a lenticular value of +1.50 D. S. (obtained by setting the front dial at +0.50 D. and the second dial at +1.00 D. S.) before the eye when using the retinoscope at a working distance of 26 inches. If the eye is emmetropic, a neutral movement (or shadow) should be observed in all meridians. An additional +0.25 D. S. (*i. e.* total of +1.75 D. S.) obtained by turning the front dial temporally two steps should give a rapid "against" movement if an emmetropic condition exists, provided (a) the refraction is along the visual axis and in the visual zone and (b) a plano mirror is used. (If a concave mirror of short focal length is used, there will be a rapid "with" movement under the condition just stated.) Again, turning the front dial nasally so as to reduce the lenticular power to +1.25 D. S. will give, in emmetropia, a rapid "with" movement, using a plano mirror.

I. Hyperopia

If, with a +1.50 D. S. before the eye, and using a plano mirror at a working distance of 26 inches, a "with" movement is observed in all meridians, a condition of hyperopia exists. One then proceeds to increase the convex spherical power before the eye until a neutral shadow is obtained in one or all meridians. The front dial carries convex lenses in eighth diopter steps to +0.88 D. S.; the second dial contains from +1.00 D. S. to +7.00 D. S. inclusive, while the third dial carries a +8.00 D. S. and a +16.00 D. S. It is therefore possible to increase the convex lens power by eighth diopter steps from zero to 23.88 D.

If the eye is thoroughly under the influence of a cycloplegic, *i. e.*, if the possibility of accommodative action is eliminated, the examiner may proceed to make his retinoscopic determinations by one of two methods: (1) Converting a condition of hyperopia into an artificially created myopia by initially overcorrecting the refractive error skia-

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scopically causing "against" movement and then reducing the convex lens power before the eye until a neutral shadow is obtained, or (2) increasing the convex lens power before the eye until the "with" movement is replaced by a neutral shadow. If the first method is followed, the procedure is identical with that described in succeeding paragraphs under the caption "Myopia." If the second method is followed, the retinoscopist, after placing the lenticular quantity before the eye which represents the dioptric equivalent of his working distance, proceeds to increase the convex lens power until a condition of neutral shadow is found to exist. This is very readily accomplished with the Phoroptor, for the examiner can increase the lenticular values (by steps of an eighth diopter if desired) by rotating the appropriate dial temporally. (See Chapter II.)

If a certain lens value, say +5.25 D. S., gives a neutral shadow in all meridians with a 26 inch working distance, the static retinoscopic finding is recorded as +3.75 D. of hyperopia (*i. e.* +5.25 D. S. − 1.50 D. S.) If there is no movement in one meridian, but a "with" or "against" movement in the meridian at right angles, the examiner knows that he has a compound error. The battery of cylindrical lenses in the Phoroptor consists of concave or minus cylinders. The examiner should always proceed to neutralize, in a case of *compound hyperopia*, the retinoscopic movement in the meridian of *maximal* error first of all with convex lenses and then use the battery of minus cylinders to correctly neutralize the retinoscopic shadow in the meridian of least power. As illustrating the points discussed, we give the following citations, all data being obtained with a plano mirror at a working distance of 26 inches.

Case I. +1.50 D. S., neutral shadow in all meridians. No refractive error.

Case II. +2.75 D. S., neutral shadow in all meridians. 1.25 diopters of hyperopia.

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Case III. +4.25 D. S., neutral shadow in vertical meridian: −1.50 D. cylinder, neutral shadow in horizontal meridian. The correction corresponds to +4.25 D. S. ⊃ −1.50 D. cyl. ax. 90, which, allowing +1.50 D. S. for the working distance, indicates a refractive correction of +2.75 D. S. ⊃ −1.50 D. cyl. ax. 90.

Myopia

If, with +1.50 D. S. before the eye and at a working distance of 26 inches, an "against" movement is noted with a plano mirror, a condition of simple or compound myopia is indicated. Reductions in lenticular values before the eye may be made in steps of an eighth of a diopter by turning the front dial *nasally*. If an "against" motion still persists when all dials read zero, the operator should then turn the front dial and the second and third dials *nasally* one step (which will insert simultaneously a −8.00 D. S. in the third dial, a +7.00 D. S. in the second dial and a +0.88 D. in the first dial before the eye), making a total of −0.12 D. If there is still an "against" movement, turn the front dial nasally step by step, which will thus increase the minus lens values in steps of an eighth of a diopter; or turn the first dial by double steps, which will increase the minus lens correction at the rate of a quarter of a diopter. If, when the first dial reads 0.12 D. S. the other two dials remaining in their initial positions, there is still an "against" movement, turn the first and second dials *nasally* one step (still leaving the third dial in its previous position) which will then place the −8.00 D. S. in the third dial before the eye together with a +6.00 D. S. in the second dial and +0.88 D. S. in the first dial giving a lenticular value of −1.12 D. S. If, after proceeding as outlined, the shadow in all meridians is still not neutralized, then turn the first and second dials *nasally* one step, leaving the third dial in its previous position, which will place −2.12 D. S. before the eye. By continu-

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ing these reductions step by step a lenticular value of −8.00 D. S. may be reached. If the shadow is still "against" with a −8.00 D. S. before the eye under examination, then turn the first, second and third dials *nasally* one step, which will insert −8.12 D. S. before the eye.

By means of the −16.00 D. S. and the −24.00 in the third dial it is possible to obtain skiascopic corrections as high as −24.00 D. S. by rotating first and second dials as previously described in steps of 0.12. Higher myopic findings may be obtained by decreasing the working distance if necessary. For example, if the shadow is neutral in all meridians with −24.00 D. S. in place and working at 8 inches, then the refractive correction skiascopically indicated is −29.00 D. (*i. e.* −24.00 D. S. and −5.00 D. S.).

Obviously in cases showing a very sluggish "against" movement, the examiner will very likely make his lenticular changes quite rapidly by rotating the second dial *nasally* one step at a time, which will increase the myopic skiascopic correction by a diopter at a step. The elasticity of procedure afforded by the arrangement of lenses in the dials of the Phoroptor permits the examiner to vary his rate of changing lens power to conform to the case in hand.

In cases of compound myopia, correct the meridian with minimal myopia first of all with concave lenses, and then adjust the axis of the cylindrical battery of lenses to parallel the meridian which has been corrected, finally neutralizing the second or more highly myopic meridian.

As simple illustrations we cite the following examples, using a plano mirror and a working distance of 26 inches:—

Case 1. +0.75 D. S. neutralizes all meridians. Correction, −0.75 D. S., since we have to allow a −1.50 D. S. for the working distance (+0.75 D. and −1.50 D. = −0.75 D.).

Case 2. No lenses before the eye under test. Shadow neutral in all meridians. Correction, −1.50 D. S.

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Case 3. The horizontal meridian is neutralized with a −4.25 D. S. and the vertical meridian with a −2.25 D. cyl. ax. 175, hence indicating upon the spherical and cylindrical lens dials −4.25 D. S. ⊃ −2.25 D. cyl. ax. 175°. Allowing −1.50 for the working distance, the full correction is −5.75 D. S. ⊃ −2.25 D. cyl. ax. 175°.

II. STATIC SKIASCOPIC TESTS WITHOUT CYCLOPLEGICS

When cycloplegics are not used, or in the pre- or post-cycloplegic examinations, the so-called "fogging system" should be employed in static retinoscopy as well as in subjective acuity tests or in determining subjective findings. The fogging method can be practiced *par excellence* with the Phoroptor. As a matter of fact, the Phoroptor, with its unique method of obtaining any desired lens value and its instantaneous insertion of such a lens before an eye, is much more of a necessity when the fogging method is pursued than in examinations under a cycloplegic. The reason is obvious: the eye under the suppression or the relaxation induced by fogging must be kept constantly in that condition if the procedure is to be of any value: to insure this means that the lenses must be changed slowly and step by step, proceeding from maximal plus to minimal minus corrections. Furthermore, minus cylindrical lenses should always be used in the fogging method.

The simplest and safest procedure the writer believes to be somewhat as follows: With one eye (say the left one) occluded, and with the +1.50 D. S. before the right eye at a working distance of 26 inches (which may be readily obtained by reason of the fact that the reading rod is 26 inches long) note the character of the retinoscopic reflexes or shadows. If these are "with" the movements of the plano mirror in all meridians, rapidly turn lenses of higher plus power before the eye until a sluggish "against" movement is obtained. Then slowly reduce the lenticular power until the meridian

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of maximal hyperopia is found. Then proceed to finish the static retinoscopic examination by placing the battery of minus cylinders before the eye, using the minimal value of minus cylinder that will afford a neutral shadow in that meridian. Then re-examine the first meridian and ascertain whether it appears to be over- or under-corrected and make changes until a neutral shadow is obtained in all meridians. As an example: with +1.50 D. S. before the right eye, the left eye being occluded, a "with "movement is present in all meridians: with a +4.00 D. S. a fairly sluggish "against" motion exists in all meridians. Slowly reducing the plus power before the eye by rotating the first and second dials *nasally* one step, at a time, the meridian of maximal power is first ascertained and corrected. Assume, for example, that the movement in the vertical meridian is neutralized by +2.75 D. S. (This means that the error in the vertical meridian can be neutralized with a +2.75 D. S.) The retinoscopic movement in the horizontal meridian, under the procedure assumed, is therefore myopic. Placing the axis of the battery of cylindrical lenses at 90°, minus cylinders are turned into place, beginning with a −0.12 D. cyl. Assume that all movement in the horizontal meridian is corrected by a −0.75 D. cyl. ax. 90°. The indicated retinoscopic finding is +2.75 D. S. ⊃ −0.75 D. cyl. ax. 90°. Allowing 1.50 D. for the working distance, the indicated refractive correction is +1.25 D. S. ⊃ −0.75 D. cyl. ax. 90°.

As a further example, let the operator start with +6.00 D. S. in position before an eye and gradually reduce the power before this eye. Suppose that a neutral shadow is found in the horizontal meridian with a +3.00 D. S. and that in addition thereto a −1.50 D. cyl. ax. 180° neutralizes the movement in the vertical meridian. The lenses before the eye are +3.00 D. S. ⊃ −1.50 D. cyl. ax. 180°. Allowing 1.50 D. S. for the working distance, we have as the indicated correction +1.50 D. S. ⊃ −1.50 D. cyl. ax. 180, which transposes immediately to +1.50 D. cyl. ax. 90°.

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Those who do not make retinoscopic examinations under a cycloplegic should read the pages devoted to the routine of a skiascopic test with cycloplegics, since the general *modus operandi* is the same in essentials, except as pointed out in the preceding paragraphs.

III. STATIC SKIASCOPIC TESTS USING SPHERES ONLY

Many retinoscopists, whether using cycloplegics or not, prefer to neutralize each meridian separately with spheres. Such a method is satisfactory and has some advantages and some disadvantages. Chief of the advantages is the fact that the exact axis does not need to be determined retinoscopically and therefore there is no error introduced by reason of inserting cylindrical lenses at improper or "slightly-off" axes. The disadvantage, in turn, lies in the fact that the operator has not the privilege under this procedure of simultaneously seeing both meridians neutral and of judging whether he has slightly undercorrected or overcorrected either or both meridians. In case the meridians are separately refracted with spheres, and irrespective of whether or not cycloplegics are used, the data are recorded in terms of equivalent cylindrical lenses. Suppose +3.50 D. S. neutralizes the movement in the 25° meridian. This is then recorded as +3.50 D. cyl. ax. 115°. If the movement in the 115° meridian is made neutral by +2.00 D. S., then the record is made as +2.00 D. cyl. ax. 25°. The combined findings are +3.50 cyl. ax. 115° and +2.00 cyl. ax. 25°. This is equivalent to +3.50 D. S. ⊃ −1.50 D. cyl. ax. 25°. Allowing 1.50 D. for the working distance, the indicated static retinoscopic finding is +2.00 D. S. ⊃ −1.50 D. cyl. ax. 25°.

IV. STATIC SKIAMETRY AS A BINOCULAR TEST

Sheard believes in making a *binocular* static skiascopic examination after the monocular findings have been obtained. There are several advantages accruing to the

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examiner. Chief of these may be mentioned the fact that, except occasionally in cases of marked exophoria, especially at the reading point, the binocular relaxation is greater than that obtained in monocular methods, whether these be skiascopic or subjective in character. In the second place, it follows as a logical conclusion from the foregoing statement that if the binocular findings are the same or less in hyperopic conditions or, again, the same or greater in myopic cases, the examiner is given a clue as to the probable presence of complicating extrinsic muscular imbalances. Thirdly, it is a safe rule to follow in routine practice that the maximum hyperopic and minimum myopic corrections should be disclosed and recorded even though, in the light of the history of the case and other data subsequently obtained, it may appear preferable to modify these corrections. In the fourth place, it is good practice to ascertain by objective methods whether the amounts and axes of correcting cylinders are the same in binocular as in monocular fixation.

These binocular static skiascopic determinations take but a few moments to obtain after the monocular data are gotten, especially if such an instrument as the Phoroptor, or similar instrument, is used. With both eyes uncovered and wearing the monocular findings, the subject's attention is directed to a suitable fixation letter on the visual acuity chart and the indicated refractive changes made and recorded as the binocular static skiascopic findings.

RÉSUMÉ

1 Use a darkened room—not pitch dark, but enough so that the reflex from the patient's eye can be readily seen.

2 See that the patient is comfortably seated behind the Phoroptor and that the instrument is in proper adjustment.

3 When making the retinoscopic examination, wear your own refractive correction, since this ensures greater thoroughness of the examination. Many retinoscopists have correcting lenses attached to the head of the retinoscope.

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4 Use a modern self-luminous retinoscope. If you use a non-illuminating type of instrument, the source of the light should be just back of the patient's head, on a level with the top of the ear and slightly to one side. Use a frosted 50 candle power incandescent lamp enclosed in a container equipped with an adjustable or iris diaphragm.

5 Adjust your own stool so that your eyes are on a level with those of the patient.

6 Make your examination along the patient's line of vision or visual axis as nearly as possible. To do this efficiently, use the macular reflectoscope.

7 Any working distance may be chosen: 26 inches is recommended in general, as it is a very satisfactory distance for making lens changes through the rotation of the spherical or cylindrical lens dials of the Phoroptor. Twenty-six inches, as a working distance, calls for an allowance of 1.50 D. theoretically.

8 See that the patient's fixation is definite but passive. An illuminated letter, *e. g.* 200 foot letter at 20 feet, is generally satisfactory.

9 After placing before the patient's eye the lens which represents the equivalent of the working distance, examine the retinoscopic shadow in all meridians. If "with the mirror," rapidly turn dials of Phoroptor until an "against" movement is obtained in all meridians. That is to say, convert every case of hyperopia or apparent emmetropia into an artificially created condition of myopia. This is an excellent procedure irrespective of whether or not cycloplegics are used. If cycloplegics are not used, it is imperative to do everything possible to relax the accommodation, or at least to suppress its activity.

10 Reduce the lenticular power until the shadow is neutral in at least one meridian. Such a condition indicates a compound refractive error. If the eye is, under a given lens power, retinoscopically neutral in all meridians, the re-

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fractive condition is hyperopia, emmetropia or myopia depending upon whether the total lens quantity before the eye under examination is greater than, equal to, or less than the dioptric equivalent of the working distance.

11 If the refractive error is a compound one, *i. e.* in which one principal meridian has a greater error than the meridian at right angles, the complete retinoscopic findings may be obtained through neutralization of the shadow movement in one meridian and the use of the battery of cylinders in the Phoroptor to compensate for the astigmia present. Or each meridian may be examined separately with spheres, in which event the amount of astigmatism will be the difference between the powers of two spherical lenses.

12 If the shadows, instead of moving regularly from side to side of the eye and either "with" or "against" the direction of rotation or movement of the mirror, appear to split into portions (known as scissor movements) it generally signifies one of three things: (1) irregular astigmatism; (2) tilted cystalline lens or (3) lack of alignment of the various media or refracting surfaces of the eye. In such conditions as this Sheard correctly laid down the principle some years ago that the examiner should watch carefully for the line of division in such scissor movements and then refract that portion of the eye (pupil) in which the reflex contains within itself the visual axis. In many cases of this character, the data afforded by the ophthalmometer may be of very great value, and these data should be obtained, both as an aid in further refractive procedure and as a check or corroborative test.

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CHAPTER IV

DYNAMIC SKIAMETRY WITH THE IMPROVED PHOROPTOR

AS Sheard has so aptly expressed it: "Static skiascopy is an objective method for the determination of the refractive status of an eye when the eye is in a condition of passively fixating a distant object or when its ciliary muscle is under the subjugation or control of a cycloplegic. Dynamic skiametry, on the other hand, is an objective method for the determination of such lens quantities as will make the retina of the active or dynamically functioning eye and the object fixated—usually at a relatively close distance from the eye, such as the normal reading distance—conjugate. In the first named set of tests, accommodative suppression and relaxation are demanded and are necessary for correct data. In the second method, however, when normally both eyes are binocularly fixating the object under regard by reason of the stimulus to binocular single vision as supplied by the accommodative or fusional convergence, or more normally and more generally by both, and when both eyes are endeavoring to read at close range a chart or card printed in small type, there is produced a definite and probably maximal stimulus to the development of the necessary accommodative changes."

Three distinct methods of practicing dynamic skiametry are in vogue today. These procedures are known as:

1 The Cross method
2 The Sheard method
3 The observation-behind-fixation method

The first two methods differ in their fundamental conceptions of the manner of obtaining data and of their interpretation. The third method is a modification of Sheard's

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recommended routine procedure and is, in fact, to be credited to him since it was first described and advocated by him in his brochure on *Dynamic Skiametry*.

I. THE CROSS METHOD

Equal Fixation-Observation Distance

"The method of dynamic skiametry as devised by A. J. Cross, of New York, in the early '80s, consists in having the subject read the letters or count the dots on a fixation chart, arranged in a manner to be described shortly, while the examiner takes note of the character of the reflex or shadow movement in each eye, alternating the eye tested first from one eye to the other and then back again until such lens values are found as give a permanent *reversal* of shadow movement. Should the examiner find a "with" motion, using a plano mirror, he then proceeds to add such convex lenses as will give a slight overcorrection binocularly as evidenced by the "against" character of the shadows. Cross recommends the use of his own particular form of skiascope. This carries a lightweight frame attached to the mirror support and fastened in such a manner that one fixation card is slightly behind and the other slightly in front of the operator's nodal point. The fundamental notion underlying this device is that when full correction has been approximated with fixation upon the card which is the more remote from the subject's eye, a quick change to the slightly nearer fixation object is made possible and that, if there is then a reversal of shadow in passing from fixation upon the first plane to fixation upon the second one, a proper refractive finding has been made as to the assistance which a pair of eyes requires in order that the accommodative needs and the coördination and correlation of accommodation and convergence may be fulfilled. We believe that this covers, in essentials at least, the mechanical procedure involved, unless there be added to these remarks the further statement that, should an "against" movement be obtained

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with a plano mirror and with fixation and observation at any given point, concave lenses are to be added until a reversal of shadow is obtained in both eyes. The fixation point, when fixation and skiascopic observation distances are one and the same, may be varied to suit the practitioner. Commonly chosen points range from ten to twenty inches from the subject under examination. It should be remarked at this point, however, that the findings as obtained at a ten inch point, for example, need not be and ordinarily are not the same as those found with a twenty inch fixation distance."[21]

The Cross method, therefore, consists fundamentally in having observation and fixation at the same point, adding lenses until a reversal of shadow occurs. Using the improved Phoroptor, the static findings may be left before the eyes and, with observation and fixation at thirteen inches (or any other distance desired, such as ten inches) a "with" shadow will be seen in the average case which requires about +1.50 D. S. over and above the spherical of the static findings to give a reversal of shadow. Bestor[22] found that this was true. He also felt that "the difference between the dynamic and subjective examination represents a tonic contraction of the ciliary, or else presbyopia, which are physiological conditions. If due to tonic contraction it is not amenable to immediate refractive correction, although it gives us valuable advance information as to the prognosis of the static refraction. If due to presbyopia it, of course, should be given as a reading correction and the amount of presbyopia deducted to arrive at the static refraction."

In case there is a condition of astigmatism which has been neutralized by static skiascopic procedures, it is advisable to remove the cylinders and to redetermine the amount and axis of astigmatism. For it is possible that the amount of

[21]Sheard, Charles. Some comments on static and dynamic skiametry, *American Journal of Physiological Optics*, Vol. VI, pp. 527–548, 1925.

[22]Bestor, H. M. The interpretation of dynamic skiametric findings, *American Journal of Physiological Optics*, Vol. I, pp. 223–233, 1920.

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astigmia as well as its axis may differ at near fixation points from the conditions found with fixation at twenty or more feet.

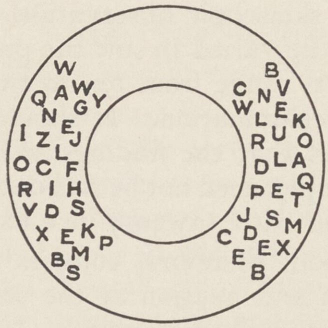

Fig. 26. Illustrating a satisfactory fixation chart for use in dynamic skiametry

As a fixation object, the letters of the alphabet may be scattered indiscriminately on a chart which may be attached to the head of the retinoscope. Such a fixation object is shown in Figure 26. Others may prefer to use the small red light which is to be found just beneath the mirror of the Giant retinoscope. The reading of letters has the advantage that it requires attention and a definite effort on the part of the patient under test to read them or attempt to read them.

II. THE SHEARD METHOD

"The procedure which Sheard follows in the case of the equal fixation-observation method of dynamic skiametry is somewhat different from that devised by Cross. Initially there is obtained by monocular static skiascopic methods those refractive findings which put each eye, in turn, in an optical condition such that the retina and the distant fixation point, passively fixated, are conjugate after due allowance has been made for the working distance. All lenses used, including therefore both the lens values dioptrically equivalent to the working distance and the lens values repre-

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senting the static refractive error, are left before the eyes, and the subject's attention is directed to the small card of printed material attached to the mirror. The subject is then instructed to read or to attempt to read or decipher the letters on this card. The direction of movement of the shadow is quickly noted in each eye and such spherical and cylindrical changes made as will afford a *neutral* shadow in all meridians in each eye. We ordinarily make the fixation-observation distance the same as that at which the person under test carries on ordinary reading or other close work. Since this distance commonly ranges between ten and sixteen inches, we generally take approximately thirteen inches as the equal fixation-observation distance. Readings at other equal fixation-observation distances may be taken if desired, but our experience is to the effect that little if any data of additional value will be obtained. Since we usually make our static retinoscopic findings at a working distance of 26 inches, theoretically demanding an allowance of about 1.50 D. in the objective estimate of the refractive error, and since experience has shown that a lag of accommodation behind convergence of about one-half to three-quarters of a diopter exists at a 13 inch fixation point, we interpret a *neutral* dynamic skiascopic finding at the 13 inch fixation-observation distance, obtained with the *total* lens quantities used in static skiascopic determinations left in place before the eyes, as indicative of the following: (1) The static retinoscopic findings are correct, (2) these findings will be satisfactory for both distant and close vision and (3) the relationships between accommodation and convergence are normal. Stated in other words and independently of the mechanical procedure pursued in making these tests, we believe that *normally* the dynamic skiascopic findings, with equal fixation-observation distances (approximately 13 inches), will exceed the static retinoscopic findings by about three-quarters of a diopter. If the dynamic findings should

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exceed the static retinoscopic determinations by more than three-quarters of a diopter in either emmetropia or hyperopia or should be decreased by more than a like amount in myopia there is objective evidence of one or more of the following: (1) Static under-correction of hyperopia or over-correction of myopia, (2) spasm of accommodation, (3) subnormal accommodation, (4) presbyopia, (5) marked extrinsic muscular defects interfering with the normal functioning of accommodation.

ILLUSTRATIVE CASES

"A few illustrations may be of value, particularly as evidencing the character of data and conclusions drawn.

"Case 1. Aged 20. Static retinoscopic findings, O. U. +1.00 D. S. Dynamic skiametric findings, 13 inch fixation and observation point, O. U. +2.00 D. S. Conclusion: Probability that O. U. +1.00 D. S. to +1.25 D. S. will be satisfactory from all standpoints.

"Case 2. Aged 20. Static findings, O. U. +1.00 D. S. Dynamic findings, O. U. +3.00 D. S. Conclusion: Either one or more of the five interferences rehearsed in a foregoing paragraph.

"Case 3. Aged 60. Static findings O. U. +1.00 D. S. Dynamic findings O. U. +3.00 D. S. Conclusion: Presbyopia, of which the amount objectively determined at a 13 inch fixation-observation distance is +1.50 to +2.00 D.

"Case 4. Aged 20. Static findings O. U. −1.00 D. S. Dynamic findings, 13 inch fixation-observation distance, O. U. −0.25 D. S. Conclusion: Probability that O. U. −1.00 D. S. will be satisfactory from all standpoints.

"Case 5. Aged 20. Static findings O. U. +2.00 D. S. Dynamic findings O. U. +1.75 D. S. (Or analogous findings in myopia, such as static findings O. U. −2.00 D. S., dynamic findings O. U. −2.25 D. S.). Conclusion: Possibility of static over-correction in hyperopia or under-

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correction in myopia. Probability, however, that one or more of the five interferences rehearsed in a foregoing paragraph are responsible for the abnormally related static-dynamic findings."[23]

The Sheard method of practicing dynamic skiametry therefore uses equal observation and fixation distances but, instead of adding lens power until a reversal of shadow occurs, sufficient plus lenses are added until a *neutral* shadow is obtained. From this result Sheard deducts one-half diopter in hyperopia and adds one-half to three-quarters of a diopter in myopia to compensate for what he calls the lag of accommodation behind convergence.[24] This method is more than an objective method of determining the refractive needs of an eye, for it permits of an objective study of the intimate relationship that exists between accommodation, accommodative convergence and fusion convergence.

III. THE OBSERVATION-BEHIND-FIXATION METHOD

In his Ettles Memorial Lecture[25], Sheard says: "Another method of testing is to take a pair of emmetropic eyes and have them fix a small letter on a quarter inch fixation, card held on a thin rod, and to then determine the point of neutral shadow skiametrically. In such emmetropic eyes, or those which have been rendered so artifically in so far as refractive errors are concerned, we have found that the neutral or reversal point is slightly farther from the patient's face than the fixation point, irrespective of the position of this point." We see that the observation-behind-fixation is essentially the same as recommended by Sheard. The difference is that, whereas Sheard in his original methods deducts and adds one-half to three-quarters of a diopter of plus

[23]Sheard, Charles. Some comments on static and dynamic skiametry, *American Journal of Physiological Optics*, Vol. VI, pp. 527–548, 1925.

[24]Sheard, Charles. Lag of accommodation, *Dynamic Skiametry*, pp. 18–20, 1920. Cleveland Press, Chicago.

[25]Sheard, Charles. The comparative values of various skiametric methods, *American Journal of Physiological Optics*, Vol. III, pp. 177–208, 1922.

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lens power in hyperopia and myopia respectively for the lag of accommodation behind convergence, this method makes the allowance by altering observation and fixation points.

Figures 27 and 28 graphically illustrate the optical

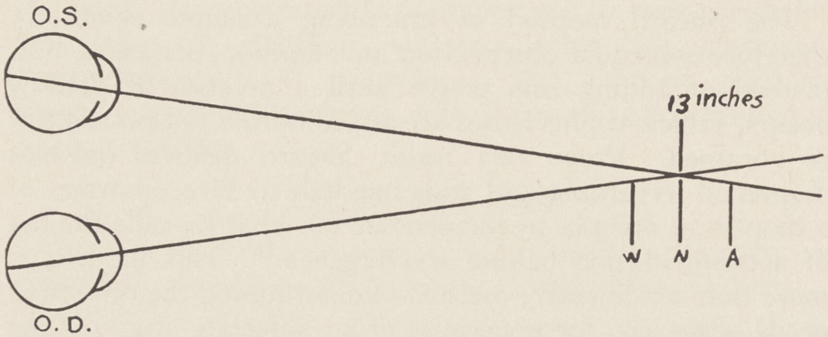

Fig. 27. Theoretically correct optical conditions of "against", "neutral" and "with" shadows in dynamic skiametry

principles involved in allowing for the lag of accommodation behind the fixation (convergence) point and indicate that, normally, a neutral shadow will be observed at sixteen inches with fixation at thirteen inches.

For example, if the eyes are emmetropic or have been

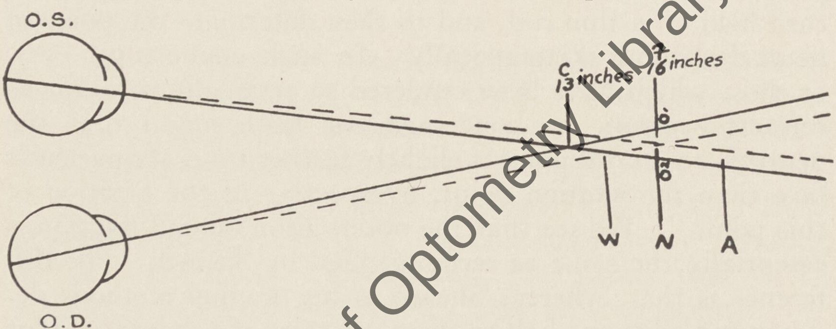

Fig. 28. Optical principles involved in allowing for the lag of accommodation behind the fixation (convergence) point

rendered so through proper lenticular corrections, and the patient fixes at thirteen inches and is able to see clearly and singly at this distance, and if there is a lag of accommodation

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behind convergence of about a half diopter, the patient will accommodate for sixteen inches while convergence is at thirteen inches. Therefore, by this method no allowance of any kind is necessary.

This method is a rapid one. It is best to leave the static findings in place, removing only the cylinders, if any, to see that the astigmatism is the same for near as well as distant fixation points and to check up on the axis. In a fair majority of the cases in young people, the static and dynamic findings are comparable so that few lens changes are necessary. By receding two inches an "against" movement of the shadow is seen, and by advancing two inches closer than the original observation point a "with" shadow is found. When this condition occurs, accommodation is lagging behind convergence in a normal manner.

Table Showing the Dioptric Value of the Reversal Point, Fixation Point, and the Dioptric Value of the Lag of Accommodation

(After Sheard)

Skiametric Point of Reversal (inches)	*Dioptric Value of Reversal Point*	*Patient's Fixation Point (inches)*	*Dioptric Value of Fixation Point*	*Dioptric Difference (Lag of Accommodation)*
16	2.50	13	3.00	0.50
15	2.60	13	3.00	0.40
12	3.30	10	4.00	0.70
10	4.00	8.5	4.70	0.70

In young patients in which additional plus spheres are needed in order to give neutral shadows, we suspect an overstimulation to the ciliary muscles. Almost invariably it will be found that the accommodation-convergence tests show an esophoric condition, which may require additional plus lens power over and above the static and subjective

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findings in order to properly alleviate conditions. Thus the muscle tests at the reading point are in agreement with the findings obtained by dynamic skiametry.[26]

Occasionally we find that minus spheres of varying amount have to be added to the static findings. Such findings, we believe, indicate that we should proceed carefully in prescribing full plus lenses in cases of hyperopia or under-

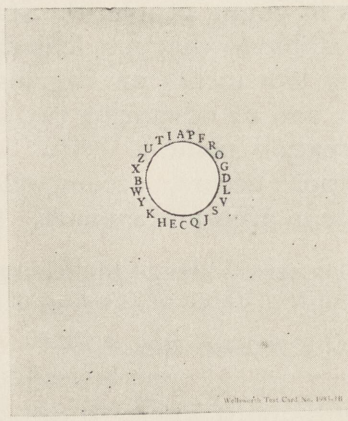

Fig. 29. Dynamic skiametric fixation card supplied with the improved Phoroptor

corrections in cases of myopia when these conditions are found. The accommodative convergence tests generally will show, in such cases, a relatively high exophoria, with low positive reserve fusion convergence. Such data are in agreement with the dynamic skiametric findings and indicate that plus spheres must be eliminated or cut down and the demand upon the fusion convergence lessened, or the reserve convergence raised, or both.

In advanced presbyopia the method of observation-behind-fixation is not advocated because, where there is

[26] Nott, I. S., Dynamic skiametry in theory and practice, *American Journal of Physiological Optics*, Vol. VI, pp. 490–503, 1925.

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little or no accommodation present, there cannot be much lag of accommodaton behind convergence.

As astigmatism due to oblique observation is an important element in any skiascopic test, it is highly desirable, in the interest of accuracy, that the examination be made as closely as possible along the patient's visual axis. For proper fixation there is supplied with every improved Phoroptor a suitable chart for dynamic skiametric observations.

The dynamic skiametric fixation card carries an aperture of about three-quarters of an inch diameter. Around this opening are placed letters of the alphabet in a haphazard manner. The person under test is asked to read these letters in a clockwise direction and vice versa.

Table Showing Observation Fixation Distances

If fixation is at 13 inches, make observation at 16 inches
If fixation is at 16 inches, make observation at 20 inches
If fixation is at 18 inches, make observation at 22 inches
If fixation is at 22 inches, make observation at 32 inches

The reading rod of the improved Phoroptor is graduated in inches, centimeters and diopters, hence it is a very easy matter to quickly set and take positions for both fixation and observation distances.

Because of its simplicity and rapidity of lens changes, both as regards its spherical or cylindrical elements, the Wellsworth Improved Phoroptor is a decided aid in any method of procedure in dynamic skiametry. The improved Phoroptor reduces the time element involved to a minimum and permits of a refractive technique which would be well-nigh impossible with the use of lenses laboriously selected from the trial case.

IV. OBJECTIVE (SKIAMETRIC) METHOD OF DETERMINING THE AMPLITUDE OF ACCOMMODATION.

In 1917 Sheard presented a simple skiascopic method for the determination of the amplitude of accommodation. For

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full particulars, reference should be made to his two volumes on *Dynamic Ocular Tests* and *Dynamic Skiametry*.

In testing for the near-point objectively Sheard proceeds as follows: The patient draws the test-object (usually a line of type in about 12 point capitals upon a card about a

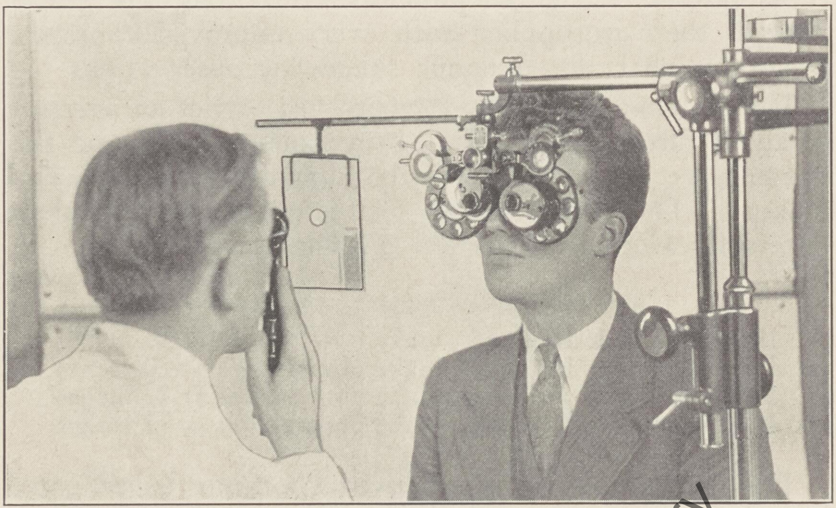

Fig. 30. Showing the dynamic skiametric card in actual use on the improved Phoroptor

quarter of an inch wide and fastened to some convenient but narrow holder) as near the eye as will still permit of its being

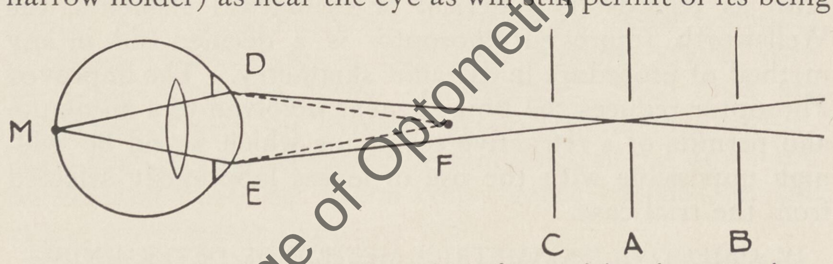

Fig. 31. Showing the skiascopic method of determining the near point

easily read. To the observer stationed at, say, sixteen inches, the skiascopic reflex will show an "against" or myopic

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condition, indicating that he is outside of the optical ocular far-point dynamically considered. In general, when this test is made, the full static corrections or reading corrections in cases of presbyopia are worn by the person under examination. The operator then moves forward with his retinoscope until he obtains a neutral shadow. The test-object is then to be carried still closer to the eye (blurred vision or inability to read is of no consequence in this test) and the nearest point of neutral shadow found and measured. It is to be emphasized that the distance to be measured is the distance from the observer's eye to the operator's eye and *not* the fixation object. This gives the apparent near-point under whatever ocular conditions the test is made (when wearing the distance correction), and from these data the range and amplitude of accommodation are easily determined.

These tests suggest their value to the examiner in finding the range and amplitude of accommodation of children; in presbyopia; in subnormal accommodation; in excessive accommodation; in amblyopia, when we are uncertain whether or not accommodation is still active because of the uncertainty of subjective tests by reason of the reduced visual acuity, and in anisometropia.

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CHAPTER V

SUBJECTIVE TESTS USING THE IMPROVED PHOROPTOR

SINCE retinoscopic tests—at least by the static method—have become today almost universally a part of the routine practice in the examination of every pair of eyes, it follows that the subjective tests will be made immediately after ophthalmoscopic, ophthalmometric and skiascopic examinations and before making the muscle tests. Lionel Laurance says: "Both objective and subjective testing have their special merits and I think that it is commonly recognized that objective tests should be made preliminary to the subjective or, to put it in another way, the objective should be confirmed by the subjective and that, on this latter, depends the final decision of the lenses best suited for a given case."[27] Many will question the latter portion of these remarks. However, be that as it may, subjective tests, in the interests of both monocular and binocular vision *only* are highly essential and necessary. Objective tests and muscular imbalance data and findings upon the *status quo* of the accommodation, and so forth, are made in the interests of the proper coördination of the functions of accommodation and convergence with the production of the highest degree of visual acuity permissible.

THE FOGGING METHOD

This method simulates the static or cycloplegic method, as the ciliary muscle is in great part placed artificially at rest by having in front of the eye under examination a *plus sphere of sufficient strength to more than overcome any ciliary muscle power that the eye might otherwise use when looking at a distance of six meters.*[28] The eye under examination with

[27]Laurance, Lionel. The routine of subjective testing. *Optometric Studies*, 1921.

[28]Thorington, James. *Methods of Refraction*, P. Blakiston's Son & Co., 1916.

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this strong plus sphere in front of it is, to all intents and purposes (at least for the time being), myopic. If the eye is over-corrected with plus spheres while looking at the distance test-chart, the desire to see as clearly as possible will induce the ciliary muscle to relax.

MODE OF PROCEDURE

The remarks which follow illustrate the general procedures which may be followed advantageously in subjective testing.[29]

Emmetropia

Visual acuity 20/20. With +1.00 D. S., V. A. is reduced to about 20/40 and little if any error is suspected.

When vision is fogged from normal to about 20/40, the eye is in about the right condition for the discovery of astigmatism, and all cases are fogged to that amount before reference is made to the astigmatic chart.

The patient's attention being directed to the astigmatic chart, all lines are reported as equally clear and distinct. Visual acuity is reduced gradually by 0.12 or 0.25 D. at a time and if best vision is secured with all lens power removed, the examiner regards his subjective test as evidencing monocular emmetropia.

In the use of the fogging method it is to be pointed out that the batteries of lenses in the Phoroptor provide the examiner with the only satisfactory method of making changes in lens power before the eye.

Hyperopia

If the error is small the visual acuity will be normal or slightly better. In this case it is usually good practice to

[29]Laurance, L. *Visual Optics*, School of Optics, London, 1926.

Smith, H. *Applied Refraction*, P. Blakiston's Son & Co., 1927.

Davis, A. E. *Refraction and Accommodation of Eye.* American Encyclopedia of Ophthalmology, Vol. XIV, Cleveland Press, 1919.

Brown, C. H. *Opticians' Manual*, Vols. I and II. Keystone Publishing Co.

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place a +2.00 D. S. before the eye and to slowly reduce the lenticular power until a visual acuity of about 20/40 is reached. Reference is then to be made to the astigmatic chart. If no astigmatism is present, reduce the lens power by steps of 0.25 D. or 0.12 D. until vision is normal. It is always a safe rule to follow to leave before the eye the maximal amount of plus lens that will afford normal acuity.

Myopia

If, for example, an eye with no lens before it has a visual acuity of 20/40 and, with +1.00 D. S. before it, is fogged to 20/80, the examiner may conclude that he has a case of myopia (either compound or simple). If no astigmatism is found, increase the minus lens power by 0.12 or 0.25 at a step until a lenticular value is reached which affords the best vision and which is to be recorded as the monocular myopic correction.

It is a safe rule to follow to give the minimal amount of minus lens power which will afford normal vision. The prescribing of −0.25 D. S. is to be especially guarded against for, as one well-known authority has said: "The good Lord made all of the contents of the trial case except the minus quarter diopter spheres and cylinders and the devil got his fingers in at these points."

Simple Astigmatism

Assume a case of astigmatism with visual acuity of 20/40. With the addition of +1.00 D. S. vision is not improved but +1.50 D. S. definitely blurs this line, so return is made to +1.00 D. S.

Attention is directed to the astigmatic chart, consisting of properly placed and spaced radiating lines of the Lancaster type. (Fig. 32.) Ascertain the meridian of blackest lines. Since the patient, during a proper fogging test, should always be optically left in a condition in which all

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meridians are focused in front of the retina before any tests are made as to the amount and axis of the astigmia, it follows that *minus* cylinders should be used and their axes placed at right angles to the direction of the reported blackest line (or lines).

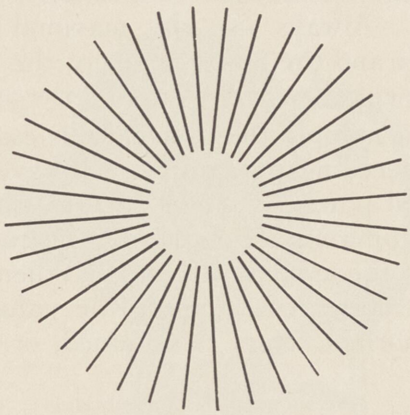

Fig. 32. The Lancaster astigmatic chart

Minus cylinders are then turned before the eye, through the medium of the battery of cylindrical lenses, by steps of 0.12 D. or 0.25 D. until the point is reached that the patient reports all lines "equally black, clear and distinct." In asking as to the black lines on the astigmatic chart, do not ask which lines are the blackest (after the axis of astigmatism has been discovered), but if the lines are equally black, clear and distinct.

It is good practice to employ the lowest value of minus cylindrical lens power that will afford equality of lines on the astigmatic test chart.

Compound Astigmatism

In compound hyperopia, the fundamental procedure is to over-correct all meridians, slowly reduce the fog by decreasing, step by step, the plus lens power until a given sec-

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tion of the lines on the astigmatic chart show up very black or plainly. Then, using the battery of minus cylinders, turn before the eye astigmatic corrections step by step until all lines become uniformly black or are equal, then turn to the test letters and decrease the power of the plus spheres until visual acuity is brought to normal or as near normal as is possible. Always use the maximal power of plus spheres possible and the lowest value of the minus cylinders which will give equality of the lines on the astigmatic chart.

In compound myopia the procedure is essentially as outlined in the preceding paragraph. However, in this case, use the minimal power of minus spheres which will permit the patient to differentiate clearly the inequalities of blackness in lines on the astigmatic chart. When the astigmatic error has been corrected, increase the value of the minus spheres until normal acuity is obtained, or as near normal as is possible.

Ophthalmometric Determinations

The ophthalmometer is of great assistance in the determination of the axis and amount of corneal astigmatism. While it may not measure the whole of the astigmatic error, since lenticular astigmatism may be present, the findings are of great assistance in the determination of the probable axis of astigmatism and are of particular value in large amounts of astigmatism and in the determination of regular astigmatism when compounded with irregular astigmatism. It is not the purpose of this manual to discuss the ophthalmometer and its uses. This has been done elsewhere.[30] It is desirable, however, to state the rules of Javal:

1 If there is no ophthalmometric astigmatism, we generally find a slight subjective astigmatism against the rule of

[30]Davis, A. E. Refraction and accommodation of the eye. *American Encyclopedia of Ophthalmology*, Vol. XIV, Cleveland Press, 1919.

Ryer, E. LeRoy. *Ophthalmometry*. Optical Publishing Co., New York, 1925.

Sheard, Charles. Ophthalmometry in ocular refraction. *American Journal of Physiological Optics*, Vol. I, pp. 357–397, 1920.

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about a half to three-quarters of a diopter. This condition would call for corrections involving plus cylinders at or in the vicinity of 180° or minus cylinders at or in the vicinity of 90°.

2 If the ophthalmometric astigmatism is against the rule, the subjective astigmatism is usually against the rule and of a greater amount.

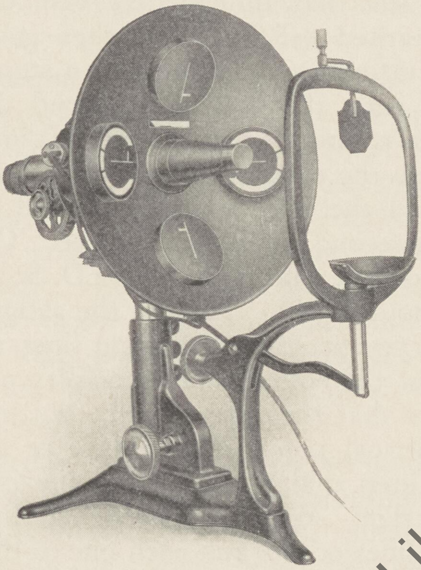

Fig. 33. The One Position Ophthalmometer

3 If the ophthalmometric astigmatism is with the rule and of a value between one and three diopters, the subjective astigmatism generally differs only slightly from it.

4 If the ophthalmometer gives an astigmatism with the rule and greater than three diopters, the subjective astigmatism is also with the rule and frequently greater.

ROUTINE OF A SUBJECTIVE TEST WITH THE MODERN PHOROPTOR

After having determined the visual acuity monocularly, occlude one eye and place in front of the eye under test such

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spherical power as will definitely fog the vision. Assume the case to be one of compound hyperopic astigmatism, *i. e.* + ⊂⊃ + correction demanded. Starting with a visual acuity of the naked eye equal, let us say, to 20/30 with a +5.00 D. S. before the eye, let us assume that the acuity is 20/100. The +5.00 D. S. is placed before the eye by turning the second lens dial, immediately behind the first dial, to the point marked +5.00. It is then good practice to reduce the fog initially a half diopter at a step. To do this, simultaneously turn the first and second dials one step nasally and then rotate the first dial until 0.50 D. is reached. The value before the eye is then 4.50 D. Turning the first dial nasally until the zero point is reached will leave the +4.00 D. in the second dial before the eye. Continuing this process, let us assume that with +3.00 D. S. before the eye, the acuity is about 20/40. Turn to the astigmatic chart of the Lancaster type or single radiating lines and determine from the patient the equality or inequality of all lines. If the patient says that they are all alike but very indistinct, reduce the spherical power from a half to a quarter of a diopter at each step, making the test on the astigmatic chart with each reduction. With proper fogging, if no inequalities of blackness of lines occurs and each line of the test chart is read under sufficient reduction in fog, then no subjective astigmatism has been disclosed.

If, however, as reduction of fog is carried on, the patient reports inequality of blackness of lines, the examiner then determines the meridians of blackest and most indistinct lines. The axis of the concave cylinder should be placed at right angles to the most distinct or blackest lines, or along the direction of the least distinct lines. The battery of minus cylindrical lenses is, therefore, swung into position before the eyes under test and the axis set as stated above. Begin by turning in a −0.25 D. cylinder in the front disc and increase by steps of a 0.12 D. up to −0.50 D. If a

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greater amount of astigmatism exists, turn both cylindrical lens discs temporally one step, which will insert a −0.63 D. before the eye and proceed by further manipulation of the front cylindrical disc. When the astigmatism is corrected through the use of the minimal amount of minus cylinder, finish the monocular subjective test by reduction of plus spherical power until normal acuity or as nearly normal acuity as is possible is reached.

In the correction of astigmatism by this method, when the eye has been fogged to 20/40 by the spherical lens, it may happen that a strong minus cylinder is required, and that, after the astigmatism is corrected, upon return to the letter chart, the visual acuity may be found to be 20/20 or better, without any additional change in the power of the spherical element. In that event, definitely fog the eye again and return to the astigmatic chart and, under a greater degree of fog than previously existed, prove out the full correction of the astigmatism, making any change in the strength of the cylinder when found.[31]

The procedure in a case of compound myopia is the same as that outlined in the preceding paragraphs with the exception that the *minimal* amount of minus sphere is used which will permit the person under test to determine the equality or inequality of lines upon the astigmatic chart. At this point correct the astigmatic error and proceed to finish the subjective tests by changing the minus spherical power before the eye, using the minimal value of minus spherical power possible.

The use of the batteries of lenses in the Phoroptor in a case of myopia, simple or compound, is as follows: First turn all dials to zero. Turn the first, second and third dials simultaneously nasally one step. This will place a −8.00 D. S. in the third dial, a +7.00 D. S. in the second dial and

[31]Maybee, W. G. *Refractive and Accommodative Errors.* Department of Education, American Optometric Association, 1920.

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a +0.88 D. S. in first dial, making a total of −0.12 D. S. By turning the first dial nasally one step at a time, the minus power may be increased at the rate of 0.12 D. S. When the zero position of the first dial is reached, there is a −1.00 D. S. before the eye. To increase the minus power by steps as small as 0.12 D. S. turn both the first and second dials nasally one step, leaving the −8.00 D. S. in the third dial in its original position. This will insert a −1.12 D. S. before the eye. The procedure as outlined is to be continued *ad libitum* until the vision is raised to about 20/40, when astigmatic tests and corrections should be made. The subjective examination is then completed by increasing the power of the minus spheres until the best monocular acuity is obtained.

Some refractionists advocate the use of *plus* cylinders instead of minus cylinders in carrying out the fogging procedure. The method is to place the plus cylinder before the eye in successive strengths with their axes over the center of the blackest and clearest lines, until all lines are equally blurred. The argument advanced is that the meridian nearest the retina is moved further forward and thus the chances of accommodative action are lessened, since the eye is thus rendered more highly artificially myopic. The writer feels that this advantage, which may be a real one, is more than counterbalanced by the fact that a person is better able to judge between any shade of gray and black than between two shades of gray, especially when equality is almost but not quite reached.

SUPPLEMENTARY SUBJECTIVE TESTS

1 *Equalization test:* When the monocular findings have been obtained, the examiner should make tests to see whether or not the acuity of vision is equally good in both eyes. This may be done in several ways. One simple method is to quite rapidly and alternately occlude each eye with a screen

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of cardboard while the patient is looking at the 20/20 or 20/30 line, or the line of type that represents the highest acuity but which may be below 20/20. If the acuity of vision is not equal in both eyes, such equalization should be attempted by slight modifications in either plus or minus lenses. This can be readily and quickly carried out with the modern Phoroptor. The equalizing tests frequently call for the use of 0.12 D. S., since this strength of lens definitely assists in securing equal visual acuity. Since the steps in lenticular power in the modern Phoroptor are 0.12 D., it is possible to make the most exacting tests desired on this point.

Sheard[32] has given us a method of equalization which consists in the placing of sufficient prismatic power over the eyes to double a single line of type placed at the fixation point, whether this fixation point be at the distant or the reading point. For the purpose of comparing the visual acuities, the two rotary prisms are swung into operative position and about 2Δ, base down, O. D. and 2Δ, base up, O. S. are used. Ordinarily this creates a vertical diplopia. It is advisable to divide the prismatic power between the two eyes for the reason that the thickness of glass in the rotary prism units absorbs and reflects an appreciable amount of light, therefore vision is reduced to some extent when a rotary prism unit is placed before one eye only by reason of the reduction of luminosity. The reduction is equal in both eyes when equal prismatic power is placed before each eye.

The patient's attention is drawn to a single line of illuminated letters of about 20/30 value by Snellen's notation. The upper line is seen by the right eye and the lower line by the left eye. It is a simple matter for the patient to make a comparison as to whether the two eyes can see with equal

[32]Sheard, Charles. *Dynamic Ocular Tests.*

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clearness, or whether one is better than the other. In case of inequality, spherical lens changes are made until equality is obtained.

The same comparison test may be used at the regular reading distance using a horizontal line of type on the card provided with the improved Phoroptor. In the case of presbyopia, the reading correction as well as the ametropic correction should be placed before the patient's eyes.

2 *The importance of the dominant eye:* The importance of the dominant eye has been called to the attention of refractionists in recent years by Sheard.[33] Full details upon these important matters may be found in the original papers. One point which he makes and which is of particular importance is that, wherever possible, the acuity of the dominant eye should be left, in general, slightly superior to that of the non-dominant one.

3 *Binocular acuity and the binocular addition of plus lenses:* After the monocular subjective examinations and the tests for equality of vision have been made, the binocular acuity test should follow. It will be found quite generally that the binocular acuity will exceed that obtained under monocular testing. As a result, it is often possible to add binocularly from +0.25 D. S. to as high as +1.00 D. S. before the eyes without materially reducing the acuity.

This test is of great importance for it has been established that if the binocular acuity is not as great as the monocular acuity, marked muscular imbalances of the extra-ocular muscles are to be looked for and investigated as the probable contributing cause or one of the causes.

This test also safeguards the examiner who does not use cycloplegics at any time during the routine of an ocular refraction. It may be assumed without question that a safe criterion in subjective testing is to give the maximal plus

[33]Sheard, Charles. The dominant or sighting eye. *American Journal of Physiological Optics.* Vol. IV, p. 49, 1923; Vol. IV, p. 294, 1923; Vol. IV, p. 448, 1923 and Vol. VII, p. 558, 1926.

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power and minimal minus power which will afford a binocular acuity which is not below that obtained monocularly.

There are a host of niceties in subjective testing which will repay, in more ways than one, the careful study and adoption on the part of those who desire to become expert in the science and art of ocular refraction. These are partially listed in the references at the close of this chapter.

THE VISUAL ACUITY AS AN INDEX OF STRENGTH OF NECESSARY SPHERICAL LENS (PLUS OR MINUS) TO GIVE NORMAL VISUAL ACUITY

In his book on *Methods of Refraction*, Thorington devotes a chapter to this topic. To obtain his data the subjects had the ability to read 6/6 or 20/20 or more and the ciliary muscle was under the effect of a reliable cycloplegic.

It is necessary to correct the astigmatism with the proper cylinder before testing the visual acuity. Since experience has shown that nearly sixty per cent of all patients coming for correcting lenses accept lenses (either plus or minus) of less than 2.50 D. S. and obtain a vision of 20/20 or more in one or both eyes, it is possible for the busy refractionist to quickly obtain an approximately correct value of the spherical element needed by use of Thorington's table given below.

TABLE

The relationship between the visual acuity under definite circumstances as an index of the required spherical lens (plus or minus) to give normal visual acuity.

English Feet	*Meters*	*Vision at 6 Meters or 20 Feet*	*Vision in Tenths*	*Spherical Lens Required for 6/6 or 20/20 Vision*
197.0	60	6/60	1/10	2.25
98.5	30	6/30	2/10	2.00
65.6	20	6/20	3/10	1.75
49.2	15	6/15	4/10	1.50
39.4	12	6/12	5/10	1.25
32.8	10	6/10	6/10	1.00
27.9	8	6/8	7/10	0.75
24.6	7	6/7	8/10	0.50
21.8	6.66	6.66/6	9/10	0.25
19.7	6	6/6	10/10	0.00

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THE STENOPAIC SLIT

The stenopaic slit consists of an opaque disc having a slot-like opening which is used for determining and correcting astigmatism. The principle involved in the use of the stenopaic slit is that each of the principal meridians of the eye, independent of the other, is isolated and tested for its spherical error. The disc is inserted before one eye, the other being occluded. The slit is slowly revolved before the eye under test, the patient observing the test-type; the slit during rotation must be centered for the visual line. In some certain position of the slit the patient will see better than in any other; this is generally the meridian of least defect and at right angles to it is the meridian of greatest error.

If the vision is 20/20 at this point, this meridian of the eye is practically normal. If not, insert before the eye various plus spheres in the battery of lenses in the Phoroptor until the plus spherical value is obtained which gives normal acuity, or the best acuity possible. If plus spheres make vision worse, change to minus spheres and proceed to find the minus sphere which will afford best visual acuity. This sphere, whatever its value, will be a measure of the refractive error in this meridian of the eye.

Then turn the slit 90 degrees to the meridian of poorest vision and repeat the process previously described.

Record the astigmatic error as the algebraic difference between the spherical lenses used in correcting the two meridians, with its axis at right angles to the poorest meridian, and as the spherical element the value of the lens correcting the best meridian.

As an example, we cite (Fig. 34): Vision is best with slit at the 30° point; +2.00 D. S. gives 20/20 visual acuity. The vision is poorest in the 120° meridian; a −3.00 D. S. gives 20/20. In this case the meridian of greatest error is myopic; hence the algebraic difference is −5.00 D. The findings are, therefore, +2.00 D. S. ⊃ −5.00 D. cyl. ax. 30.

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As a further illustration, let it be assumed that the findings are: +3.00 D. S. with slit along the 40° line or meridian, and +5.00 D. S. at 130°. The combination needed is +3.00 D. S. ⊂ +2.00 D. cyl. ax. 40°.

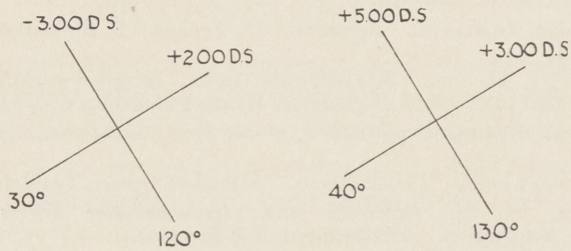

Fig. 34. Illustrating the data obtained when using the stenopaic slit in refraction

The stenopaic slit is useful in special cases, particularly in conditions of regular astigmatism complicated with irregular astigmatism, keratoconus or other fairly high astigmatic error. It is useless if the astigmatism is of low value or completely masked or if accommodation is very active.

Junés[34] has made considerable use of the stenopaic slit in routine ocular refraction. For full details, his original paper should be consulted.

[34]Junés E. Le diagnostic et la mesure des vices de refraction au moyen de la fente stenopeique. *International Congress of Ophthalmology*, p. 520, 1922. An excellent résumé of points in this method is given by Atkinson in his *Technic of Refraction*.

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CHAPTER VI

THE TECHNIC OF TONICITY OR IMBALANCE TESTS

THE COÖRDINATION TEST

THE importance of a thorough and systematic set of tests upon the poise and innervational strengths of the extra-ocular muscles is so well recognized at the present time that it is not necessary to enter into a discussion of the "whys and wherefores" of such procedures. As a well-known authority has said so succinctly: "A pair of eyes may be likened to a team of horses controlled by a teamster. The muscles are the reins by means of which the teamster, *i. e.* the controlling nervous centers, coördinates the pair of horses or pair of eyes, as the case may be. The vital question is: Are these horses or are these eyes so coördinated and harnessed together as to permit of an efficient and economically functioning pair or are they maintained in coördination through the expenditure of excessive nervous energy? To return to the analogy of the horses: Do they tend to bite each others necks or do they strive to pull away from each other, one to the right and one to the left? Or is one horse always lagging behind the other, so that the driver has to constantly restrain one horse or constantly whip up the other? To anyone who is appreciative of what this situation means, there will come an immediate realization of the significance of the drain upon the nerve centers involved in the case of pairs of eyes which, perchance, may tend to excessive convergence, divergence or hyperphoria or may actually be in a condition of over-convergence (esotropia), divergence (exotropia) or vertical imbalance (hypertropia or catatropia). In fact, the tendencies to binocular incoördinations may be much more exacting and disastrous in their final outcome than conditions of actual tropia, in which binocular single vision does not obtain."

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The initial tests upon the tonicity of the extra-ocular muscles should be made while the eyes are in a static condition, which is secured by the fixation of a spot of light or a single letter of the chart placed at 20 feet or more from the patient. Care should be exercised that the spot-light or other fixation test object is on a level with the patient's eyes and in a straight-away position, otherwise pseudo-heterophorias of various types and degrees may be found. The Phoroptor should also be properly adjusted for the inter-pupillary distance and carefully levelled: this is very important when the refractive error is high.

Care should also be exercised that there are no other lights in the field of vision of the patient other than the spot-light or Greek cross used as the test-object. Otherwise there will be a confusion of images with the consequent inaccuracy and confusion in answers on the part of the subject under test.

As a routine procedure it is generally sufficient to determine the extra-ocular muscle balance only when ametropic corrections are worn before the eyes under test. However, in many instances the refractionist will find it of advantage to make records of findings on tonicity both with and without refractive corrections, since he may thereby determine the immediate effects of proper corrective lenses upon the tendencies to imbalance.[35]

There are also occasions upon which subjects under test report inability to see the spot-light and Maddox-rod streak or second image produced by a displacing prism. In that event, it is possible that the Phoroptor is improperly placed or adjusted and may not be so placed as to give a straight-away vision or fixation of the test-object. Or a condition of suspenopsia[36] may exist. In this event the use of a colored glass (say, red) may be of great assistance. Then there are,

[35]Sheard, Charles. Asthenopia due to imbalance of the extrinsic muscles of the eye. *American Journal of Physiological Optics*, Vol. III, p. 53, 1922.

[36]McFadden, Fay. Intermittent visual perception or suspenopsia. *American Journal of Physiological Optics*, Vol. V, p. 70, 1924.

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of course, very definite physiological or pathological conditions which prevent both images being observed, such as amblyopia exanopsia, corneal or lenticular opacities, and the like.

MNEMONICS IN MUSCLE TESTING

To the beginner in the testing of the extra-ocular muscles a few simple facts will be of great value if committed to memory.

1 The image of an object formed upon the retina above the fovea is projected downward.

2 The image of an object formed upon the retina below the fovea is projected upward.

3 The image of an object formed on the retina to the nasal side of the fovea is projected toward the temporal side.

4 The image of an object formed on the retina to the temporal side is projected toward the nasal side.

As a consequence, we know that the following conditions exist:

1 *Esophoria.* Homonymous diplopia or uncrossed images.

2 *Exophoria.* Heteronymous diplopia or crossed images.

3 *Right hyperphoria.* The image seen by the right eye is below that seen by the left eye.

4 *Left hyperphoria.* The image seen by the left eye is below that seen by the right eye.

THE USE OF THE ROTARY PRISM UNITS IN THE MEASUREMENT OF OCULAR IMBALANCES

In order to assist in the proper placement and insertion of prismatic power before the eye in various conditions of muscular imbalance, the following simple statements will be of assistance.

Lateral Imbalances: Place the rotary prism unit before either eye, with its zero graduation vertical. By turning the

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unit so as to insert prism, base out, before the eye, correction is made for esophoria. An exophoria is corrected by turning before the eye prism, base in.

Vertical imbalances: Place the rotary prism unit before either eye, with its zero graduation lateral. Turning the indicator point to numbers above the horizontal dividing line inserts prism, base up, before the eye. In like manner, turning the indicator point to numbers below the horizontal dividing line places prism, base down, before the eye.

METHODS FOR DETERMINING THE CONDITION OF THE EXTRA-OCULAR BALANCE OR IMBALANCE

There are four methods which may be followed in conducting the coördination test.

1 Maddox rod.

2 Maddox rod in conjunction with the cover test.

3 Maddox double prism.

4 Fixed displacing prism.

These methods will be described in detail, as refractionists differ in their preferences in methods of conducting coördination tests.

I. THE MADDOX ROD PHORIA TEST

In order to determine what the tendency of the visual lines may be with respect to the point of fixation as disclosed by the coördination test at either the far or near point, a Maddox rod and a point of light may be employed in the following manner:

To test the lateral tendency of the visual lines when fixating at a distance, place a Maddox rod before one eye with its axis horizontal and direct the observer's attention to a point of light, which is a few millimeters in diameter and in direct vertical and horizontal alignment with the Phoroptor and some five or six meters distant in the dark room. Some question may arise as to which eye should

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carry before it the Maddox rod. Sheard[35A], Dolman[36A] and others have written much upon the discrepancies in coördination tests depending upon the eye before which the Maddox rod is placed. Sheard believes that, in the majority of pairs of eyes, one eye is dominant and that the dissociating agent, of whatever nature it may be, should always be placed before the non-dominant eye.

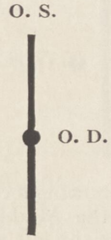

Fig. 35. Showing a condition of lateral orthophoria, using the Maddox rod and fixation source of light

With the Maddox rod before the left eye, for example, the vertical streak as seen by that eye will cut the point of light as seen by the right eye (Fig. 35) if there is no manifest disturbance of lateral coördination.

However, should the streak of light or red line appear to the observer's left side and the point of light to his right hand, the visual lines are actually crossing in that case somewhere between the observer and the point of light and a condition of esophoria exists. One of the rotary prisms, preferably the one which may be placed before the same eye as carries the Maddox rod, should now be swung into position with the zero graduation vertical and prismatic power, base

[35A]Sheard, Charles. The dominant or sighting eye. *American Journal of Physiological Optics*, Vol. III, p. 49, 1923; *ibid*, p. 294, 1923; *ibid*, Vol. III, p. 558, 1926.

[36A]Dolman, Percival. The Maddox multiple red rod. *Archives of Ophthalmology*, Vol. XLIX, p. 194, 1920; *American Journal of Ophthalmology*, Vol. III, p. 258, 1920.

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out, inserted before the eye until the spot of light and ribbon (streak or line produced by Maddox rod) are in coincidence. The amount of prism necessary for superposition of images is to be recorded as a measure of the esophoric tendency as disclosed by this method.

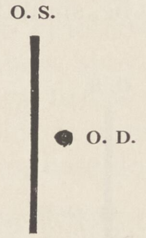

Fig. 36. Showing a condition of esophoria, the Maddox rod before the left eye

If, with the Maddox rod before the left eye, the ribbon of light is to the right of the fixation spot, a condition of exophoria exists. The amount of prism, base in, that is needed to bring the streak of light and fixation source in contact is a measure of the amount of exophoria. The rotary prism should be placed before the same eye as the Maddox rod.

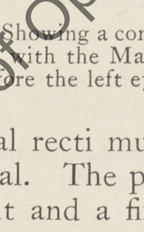

Fig. 37. Showing a condition of exophoria with the Maddox rod before the left eye

For testing the vertical recti muscles, turn the Maddox rod so its axis lies vertical. The patient should then see a horizontal ribbon of light and a fixation spot. Many ad-

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vocate that the lateral imbalance correction, if such exists, should be inserted in one of the rotary prisms and placed in front of the eyes under test before proceeding to test for vertical imbalances.

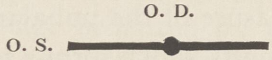

Fig. 38. Showing a condition of vertical orthophoria using the Maddox rod and distant light source

If, with the Maddox rod vertical, the ribbon of light and fixation source are in juxtaposition, as diagrammed in Fig. 38, there is no vertical imbalance.

If the ribbon of light is above the fixation light, the Maddox rod being placed before the left eye, then there is dis-

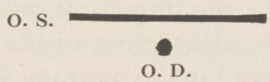

Fig. 39. Showing a condition of right hyperphoria, the Maddox rod being before the left eye

closed a tendency for the left eye to turn downward or the right eye to turn upward, which is to be recorded as right hyperphoria. The amount of prismatic power which must be inserted before the eye through the use of the rotary unit (placed with its zero graduation horizontal) is a measure of the vertical imbalance.

Fig. 40. Showing a condition of left hyperphoria, the Maddox rod being before the left eye

On the other hand, if the relative positions of fixation spot and streak are those shown in Fig. 40, a condition of left hyperphoria (right eye turning downward or left eye

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turning upward) is manifested. The amount of prismatic power (obtained through the use of the rotary prism units), placed base down before the left eye or base up before the right eye, which will cause the streak of light to cut the fixation spot is a measure of the imbalance.

The rotary prism units which form a part of the improved Phoroptor may be used with the greatest of ease and desirable speed. The openness of the scale readings makes the measurement of vertical imbalances accurately possible to a half prism diopter. Since small amounts of vertical incoördination are often very important, it can be appreciated by the reader that the muscle testing equipment leaves nothing to the imagination and eliminates guessing.

The tests which have been discussed in the foregoing paragraphs may likewise be made at the reading distance and when doing so the reading correction should be in place and the interpupillary adjustment of the instrument reduced about three millimeters for the average P. D. A very small spot of light (about 2 mm in diameter) should be employed at the reading distance as the test-object.

II. THE MADDOX ROD TEST IN CONJUNCTION WITH THE COVER OR SCREEN TEST

While the coördination tests, if made as described, will ordinarily indicate the state of interbalance of the visual lines, by reason of a reduction in the desire for fusion due to the minuteness and dissimilar character of the images as received by each eye, nevertheless it rarely if ever discloses the full or true error because of the location of the images impressed upon the two retinas within the fusion area. For that and other reasons many refractionists have discarded this classic method of conducting the coördination test.

On this topic Sheard[37] says: "Objection has been raised to the use of the Maddox rod and fixation light on the ground

[37]Sheard, Charles. *American Journal of Physiological Optics*, Vol. V, p. 207, 1924.

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that, as the streak and light are brought nearer together through the use of appropriate prismatic power, there is frequently a sudden superposition of streak and light or "jumping" of the light into the streak. This is due to the fact that, as the image produced by the Maddox rod approches the fovea of the non-fixing eye, there is a stimulus to fusion.

"Because of this tendency to fusion, the writer and others who have made tests on this point recommend the use of the cover test in conjunction with the Maddox rod. In this procedure, the eye wearing the Maddox rod is covered with a suitable screen (such as the office record card), then quickly uncovered and the relative location of streak and fixation light asked of the patient at the instant of uncovering. A correct measure of the apparent imbalance is given by the amount of prism which, under the cover test and at the instant of uncovering, shows orthophoria."

Through the use of the cover test in conjunction with the Maddox rod method of testing for coördination of the eyes, it is felt that more accurate data will be obtained through the elimination of tendencies both to accommodation and fusion.

III. PHORIA TESTS WITH MADDOX DOUBLE PRISMS

The use of the Maddox double prism in tests upon the coördination of the eyes possesses the advantage that tests can be simultaneously made and corrections applied for both lateral and vertical imbalances. If, for example, an esophoria of 8Δ exists, this can be determined by the 8Δ necessary to put the three images in alignment. The conditions of vertical balance or imbalance can then be determined with the lateral imbalance corrected. If, again, a considerable vertical imbalance exists, this can be determined and corrected, and the lateral imbalance then measured. This ability to observe the effects of the pris-

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matic correction of vertical imbalances upon lateral errors, and *vice versa*, is often of untold benefit. In cases of vertical imbalance, coupled with lateral errors, it frequently happens that the correction of a lateral imbalance shows a noticeable reduction in the vertical imbalance. Or, again, just the reverse may be true.

The Maddox double prism, when used in testing the errors of tonicity, may be placed before either eye and a red glass may be used as a filter, preferably placed before the same eye as the double prism. It is a matter of almost universal agreement that, in a monocular muscle test, the dissociating device, such as the Maddox double prism, should be placed before the non-dominant eye, leaving the dominant eye free to carry out its function of fixation.

Since the right eye is the dominant one in the majority of cases, we shall assume that the Maddox double prism and the red glass filter are placed before the left eye.

An excellent fixation target for this or the single displacing prism procedure is the Greek cross similar to that found in the Wellsworth dark-room lantern No. 625. With the right eye occluded, and the Maddox double prism and the red glass before the left eye, the patient should see two red crosses, one directly over the other. If the two crosses are not visible or if only one is clearly visible, adjust the instrument until the two are distinctly seen. The right eye is now uncovered. The subject under test should now see a third cross, ordinarily situated somewhere between the two images (upper and lower) due to the Maddox double prism. Since the double prism furnished with the Phoroptor consists of two 6Δ prisms placed base to base, the images thereby produced on the non-fixating eye are well removed, in general, from the so-called normal fusion area.

If the three images are in a vertical row (or along an assumed plumb line), there is a condition of lateral orthophoria.

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If the white cross is to the right of the two red ones there is a condition of esophoria and the amount of prism, base out—inserted in a rotary prism unit placed before the non-fixating eye (*i. e.* left eye in this case assumed) and initially

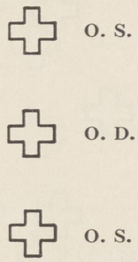

Fig. 41. Showing a condition of lateral orthophoria, using the Maddox double prism and the Greek cross

placed with its zero graduation in a vertical position—necessary to bring the three images into vertical alignment indicates the amount of esophoria present.

If the white cross, as seen by the right eye, is to the left

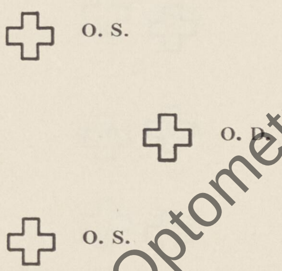

Fig. 42. Showing a condition of esophoria, using the Maddox double prism before the left eye and the Greek cross as a fixation object

of the red ones due to the Maddox double prism before the left eye, the examiner is dealing with a case of exophoria.

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The amount of prism, base in—inserted in a rotary prism unit placed before the non-fixating eye—needed in order to align the three images vertically, measures the amount of exophoric imbalance.

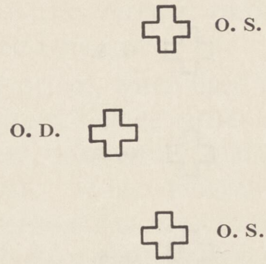

Fig. 43. Showing a condition of exophoria with the Maddox double prism before the left eye and the Greek cross as a fixation object

The tonicity of the vertical recti muscle may then be checked without altering the Maddox double prism. The rotary prism unit, however, should be turned so that its zero graduation lies in a horizontal direction (180° meridian).

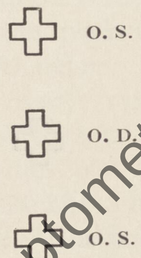

Fig. 44. Showing a condition of vertical orthophoria with the Maddox double prism and Greek cross

If the white middle cross is just half-way between the upper and lower red crosses there is a condition of vertical orthophoria.

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If the white cross is closer or nearer to the top red cross, the right eye has a downward tendency or the left eye turns upward (left hyperphoria) and the amount of prism, base up, inserted before the right eye or prism, base down, placed

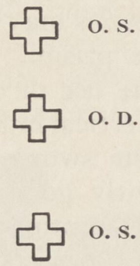

Fig. 45. Showing a condition of left hyperphoria with the Maddox double prism before the left eye and the Greek cross as a fixation object

before the left eye which will place the white cross midway between the two red ones is a measure of the vertical imbalance.

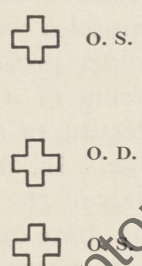

Fig. 46. Showing a condition of right hyperphoria with the Maddox double prism before the left eye and the Greek cross as a fixation object

If the white cross is nearer to the lower or bottom red cross, the left eye is turning downward or the right eye is turning upward (right hyperphoria). The amount of prism,

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base up, placed before the left eye or prism, base down, before the right eye which will bring the white cross exactly midway between the other two affords a measurement of the amount of right hyperphoria.

As previously remarked, the condition of the coördination of the lateral and recti muscles may be tested simultaneously with the Maddox double prism. The lateral adjustment may be made through the use of one rotary prism placed before one eye, while the vertical imbalance may be measured by the second rotary prism swung into position before the other eye. It is apparently good practice to correct the lateral imbalance before attempting to determine the vertical imbalance.

IV. COÖRDINATION TESTS USING THE DISPLACING PRISM

This particular method of making tonicity tests with fixation at 20 feet or more is recommended and used by many refractionists. It is easily, quickly and accurately carried out with the improved Phoroptor. Any who have been accustomed to using the Maddox rod for testing the coördination of the extraocular muscles will find this method, we believe, superior to the older procedures. The system, in brief, consists in the placing of a single displacing prism before one eye and then testing or measuring the imbalance disclosed by this same eye. In order to accomplish this, each of the two back dials of the Phoroptor carries a 10Δ prism, base in, a 15Δ prism, base out, and a 6Δ prism, base up. It is possible, therefore, to produce diplopia of either a lateral or vertical character and to measure the imbalances or tendencies to deviation of the eye before which the displacing prism is placed by the use of a rotary prism unit situated in front of this same eye.

The displacing prism, whether base in, base out, or base up, may be inserted before either eye. A red glass filter may be employed before one or both eyes. For this test an

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excellent target for fixation purposes is the Greek cross as found in the Wellsworth dark-room lantern No. 625.

The patient's ametropic correction should be placed in the spherical and cylindrical lens batteries and they should be properly centered. It is, however, often important and of great value to make all tonicity tests—if the visual acuity will permit—without corrective lenses before the eyes in order to determine the influence which such corrective lenses exert upon the coördination of the eyes.

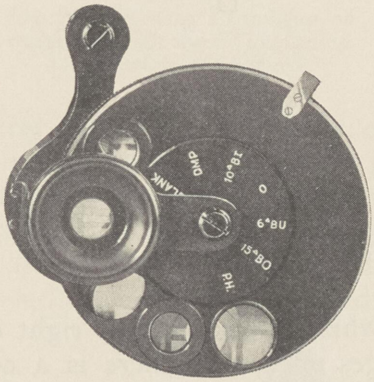

Fig. 47. Showing the back dial (reversed) of the Phoroptor set with 6^{Δ}, base up, before one eye

For the purpose of explaining that which follows we shall assume that the displacing prism and red glass are placed before the left eye and that the right rotary prism is swung into position before the right eye and placed with its zero graduation vertical, while the left rotary prism has its zero graduation horizontal.

To test for esophoria or exophoria, place before the left eye the 6Δ prism, base up, in the rear dial, together with the red glass filter. The patient should see two images (or crosses), one of which is red and the other white. The red cross is seen by the left eye below the position of the white cross as seen by the right eye. The 6Δ prism, base up, used

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as the displacing agent is generally of such strength as to throw the image received by that eye well off the fusion area. Occasionally a very considerable amount of right hyperphoria will be found, in which event the classic Maddox rod tests can be used.

If the upper white cross is directly above the lower red cross there is a condition of lateral orthophoria.

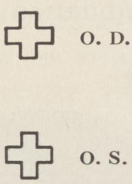

Fig. 48. Showing a condition of lateral orthophoria using a 6^{Δ} displacing prism before the left eye and the Greek cross as a fixation object

If the upper white cross is to the right of the lower red image, *i. e.* images uncrossed, there is a condition of esophoria present and the amount of prism, base out, which, when placed before either eye, produces a vertical alignment of images is a measure of the amount of esophoria.

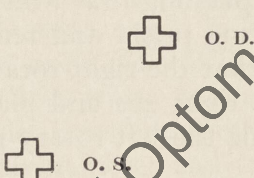

Fig. 49. Showing a condition of esophoria with the 6^{Δ} displacing prism before the left eye

If the upper white cross is to the left of the lower red cross, *i. e.* crossed images, there is a condition of exophoria

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disclosed. The amount of prism, base in, which, when placed before either eye, affords a vertical alignment of images is a measure of the exophoria.

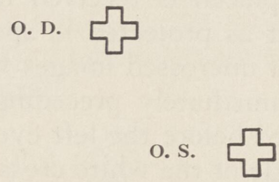

Fig. 50. Showing a condition of exophoria with the 6^{Δ} displacing prism before the left eye

When the lateral imbalance has been determined, the 10Δ prism, base in, should be turned into position (in our illustration, before the left eye). This automatically removes the 6Δ prism, base up. The 10Δ prism, base in, when in position before an eye displaces the image on its retina nasally beyond the fusion field and ordinarily produces

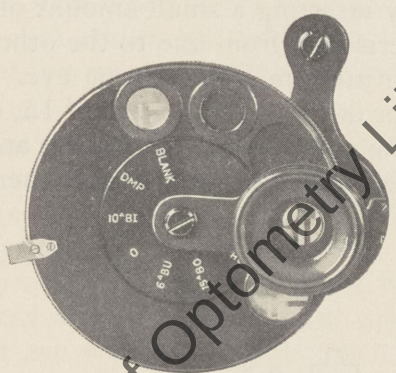

Fig. 51. Showing the back dial (reversed) of the Phoroptor set with 10^{Δ}, base in, before one eye

insuperable horizontal diplopia. Occasionally an exophoria of 10Δ or more may exist, in which event recourse may be had to one or more of the three methods previously discussed.

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Since the 10Δ prism, base in, creates, under ordinary conditions, a situation of artificial esophoria, and since the image upon the retina of the eye before which the displacing prism is placed is received nasally, the images of the fixation object as projected in space will be uncrossed, *i. e.* a condition of uncrossed images will obtain. If, therefore, as in the immediately preceding paragraphs, the red glass filter is placed before the left eye, the red cross will be seen on the left side of the white cross.

Fig. 52. Showing a condition of vertical orthophoria, using 10^{Δ} displacing prism, base in, before the left eye

If the two crosses (or images of the fixation object) appear to be on the same level there is no vertical imbalance and a condition of vertical orthophoria exists. It is well to test this situation by inserting a small amount of prism, base up or down, or alternating from one to the other, by the use of the rotary prism unit in front of one eye. An amount of prism, base up or down, not in excess of 1Δ, should elicit the response from the patient that the images are now no longer on the same level, but that one is higher then the other, and *vice versa.*

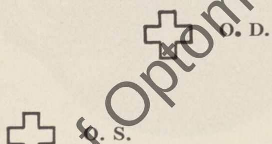

Fig. 53. Showing a condition of left hyperphoria, using the 10^{Δ} displacing prism, base in, before the left eye

If the red cross (as seen by the left eye) is lower than the white image of the cross (seen by the right eye), there is

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proof of the existence of left hyperphoria since the left eye turns upward or the right eye turns downward. This may be measured and corrected by the amount of prism, base up, which, when placed before the right eye, affords a lateral alignment of images, or again, by the amount of prism, base down, which, when placed before the left eye, brings the two images exactly horizontal.

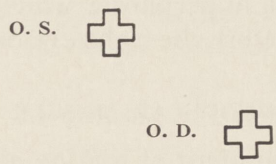

Fig. 54. Showing a condition of right hyperphoria, using the $10^{\triangle}$ displacing prism, base in, before the left eye

If the red cross, as seen by the left eye, is higher than the white one, there is a condition of right hyperphoria and the amount of prism, base down before the right eye (or base up before the left eye) which will bring the two images into lateral alignment is a measure of the amount of right hyperphoria.

All of the tests upon the vertical coördination of the eyes may be made by placing the 10Δ displacing prism, base in, before one eye (say the left one). In that event a condition of artificial esophoria will be created and, since the image of an object formed on the retina to the nasal side of the fovea is projected toward the temporal side, the image as seen by the left eye will be to the left of that seen by the right eye. If, then, the displacing 10Δ prism, base in, is placed before the left eye together with the red glass filter, the left red image is seen by the left eye and the right white image is seen by the right eye. Therefore:

1 If the two images are on a level, vertical orthophoria exists.

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2 If the left red image (as seen by the left eye) is higher than the right white image (as seen by the right eye), there is a condition of right hyperphoria which can be corrected by prisms, base down, before the right eye or base up before the left eye.

3 If the left red image (as seen by the left eye) is lower than the right white image (as seen by the right eye), there is a condition of left hyperphoria which can be corrected by prisms, base up, before the right eye or base down before the left eye.

MONOCULAR MUSCLE TESTS

A considerable amount of writing and discussion has been entered into during the past few years with regard to binocular and monocular muscle tests and their fundamental difference. All authorities are agreed that tests made with the Stevens Phorometer (which has been discarded in the improved Phoroptor), the Maddox rod test and the customary method of making a test upon the coördination of the eyes is a binocular procedure, for the reason that corrective prisms and dissociating devices are placed indiscriminately before both eyes.

In order that monocular muscle tests be properly made—whether these examinations have to do with coördination or duction powers—the dissociating or displacing instrument and the total prism power employed must be placed before one and the same eye, or the eye under test, and the fixating eye—whether it be the dominant eye or not—must carry nothing but the correcting spherical or cylindrical lenses, or both as the case may be. To repeat: the eye under test, if a monocular muscle test is to be made, must carry in front of itself both the dissociating or displacing agent and the rotary prism unit. This is possible in the modern Phoroptor. To Dr. G. C. Savage should be given credit for the conception of the necessity for monocular tests and the devising of the first monocular Phorometer.

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A résumé of the essential procedure in making monocular coördination tests is as follows:

1 To test the balance of the lateral recti muscles of the right eye, place the 6Δ prism, base up, in the rear dial before the right eye and measure the amount of esophoria or exophoria exhibited by that eye through the use of the right rotary prism unit.

2 To test the imbalance of the lateral recti muscles of the left eye, place the 6Δ prism, base up, in the rear dial before the left eye, leaving the right eye as the fixating member, and measure the amount of esophoria or exophoria exhibited by that eye through the use of the left rotary prism unit.

3 To test the balance of the vertical recti muscles of the right eye, place the 10Δ prism, base in, in the rear dial before the right eye and measure the amount of right or left hyperphoria exhibited by that eye through the use of the right rotary prism unit.

4 To test the balance of the vertical recti muscles of the left eye, place the 10Δ prism, base in, in the rear dial before the left eye and measure the amount of right or left hyperphoria exhibited by that eye through the use of the left rotary prism unit.

THE DOMINANT EYE

In the majority of individuals one eye is the dominant or fixating eye, while its mate is simply the "follower-up" in the act of binocular single vision. Each eye, therefore, has a rather distinctive function to perform. The *dominant* eye is the eye which sights or *locates* the object and, all other things being equal, involuntarily acts through the function of accommodation to the end that the object is seen as distinctly as possible: the non-fixating or *non-dominant* eye, on the other hand, is not fundamentally involved in sighting or in the initial impulse to distinct vision, but is the *moving*

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eye. This moving eye, therefore, operates in harmony with the sighting eye and functions in the act of convergence to the amount necessary to afford binocular single vision by moving or swinging through the requisite number of degrees. Those interested should consult the references given below,[38] and the articles containing practical suggestions by Sheard.[39]

There are several methods for the determination of the dominant eye. One of the best is that suggested by Dolman[38] and devised by him while working at the Medical Research Laboratories at Mineola, L. I. A card, about fifteen by twenty centimeters, carries at its center a hole cut almost three centimeters in diameter. The test for dominancy is made by having the person under test take the card in both hands and raise it slowly at arm's length while looking fixedly at a spot of light twenty feet away. Both eyes are to be kept open and the light is to be located through the hole. Obviously, from the simple geometry of the proposition, it is impossible for both eyes to see the light through the hole. The eye selected (involuntarily) for this purpose by the subject is the sighting or dominant eye. The test is both simple and convenient, prevents negative results and uncertainties and lessens the possibility of the influence of the right or left hand on the test.

By way of résumé upon the significance of the dominant eye in matters of visual acuity, muscular imbalance and duction tests, the wearing of prisms, prismatic exercises and operative procedures, Sheard[39] writes:

[38]Tscherning, M. *Physiological Optics*. Keystone Publishing Company, p. 308, 1904.

Maddox, E. E. *Tests and Studies of the Ocular Muscles*. Keystone Publishing Company, pp. 87–94.

Gould, G. M. *Biographical Clinics*, Vol. III, pp. 363–373, P. Blakiston's Son & Co., 1904.

Dolman, Percival. The relation of the sighting eye to the measurement of heterophoria. *American Journal of Ophthalmology*, Vol. III, p. 258, 1920.

[39]Sheard, Charles. The dominant eye and its significance in muscular imbalance and duction tests. *American Journal of Physiological Optics*, Vol. IV, p. 49, 1924; *ibid*, Vol. IV, p. 294, 1924; *ibid*, Vol. VII, p. 558, 1926.

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1 In eyes having equal acuity, leave the visual acuity of the dominant eye, all other things not indicating to the contrary, slightly superior. Under no circumstances, when such can be avoided, leave the acuity of the non-directing eye better than that of the directing member.

2 In cases of anisometropia or in which the visual acuity of the dominant eye is not quite equal (say 20/30) to that of the non-fixating eye (say 20/20), it will often produce comfort and satisfaction if the acuity of the non-fixating eye is slightly reduced by additional convex lens power. Especially is this true in close work.

3 All ocular muscle tests should be *monocular*.

4 In testing for heterophoria, the testing device should always be placed before the non-dominant eye, the directing or dominant eye having nothing before it to interfere with its straight-away fixation. There seems to be but little reason for making a set of tests in the reverse manner.

5 In making duction tests, especially upon the lateral muscles, it would appear to be sufficient to make such duction tests upon the non-dominant or coördinating eye. In vertical directions, it is best to take them upon each eye in turn.

6 In case of tropias or phorias, in which prismatic exercises or like treatments are given, the whole of the prism should be placed before the deviating or non-fixing eye.

7 If prismatic corrections are incorporated in the glasses prescribed, then the major portion, if not the total in cases in which the total amount does not exceed 2Δ, should be placed before the non-dominant eye. If 1Δ to 2Δ, base in, out, up or down, are to be incorporated in lenses, they should be worn before the non-dominant eye. In other words, interfere to the least possible extent with the dominant eye in its function of straight-away fixation.

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METHODS OF TESTING AND MEASURING CYCLOPHORIA

But little has been written in recent years with reference to cyclophoria—a tendency of the vertical axes of the eyes to lose parallelism with the median plane of the head, or a tendency that one or both eyes may possess to rotate on the antero-posterior axis due, presumably, to an imbalance of the oblique muscles. The names of Helmholtz,[40] Volkmann, Meissner, Stevens,[41] Maddox,[42] Price and Savage[43] are at once suggested when the term cyclophoria is mentioned. With all of the experimentation of these and other learned men, there still remains much doubt as to what is to be considered cyclophoria and as to the efficacy of certain lines of treatment. Amongst the most recent articles are those by Ames[44] and Verhoeff[45], together with two papers by Sheard[46] which serve as résumé articles. For a full appreciation of the subject of cyclophoria and for a comparison of various opinions, many of which are diametrically opposed, the reader should consult the references given and the original papers mentioned in these references.

The tests for cyclophoria at a fixation distance of six meters are made by inserting in the improved Phoroptor the Maddox multiple rods, one before each eye, and in addition turning in before one eye the 6Δ prism, base up, contained in the rear cell. The eye under test is considered by some authorities to be the one carrying both the 6Δ dis-

[40]Helmholtz, H. *Physiological Optics* (English translation). Optical Society of America. Banta Publishing Company, Menasha, Wis.

[41]Stevens, G. E. *Motor Apparatus of the Eyes*. F. A. Davis and Company.

[42]Maddox, E. E. *Ocular Muscles*. Keystone Publishing Company.

[43]Savage, G. C. *Ophthalmic Myology and Ophthalmic Neuro-Myology*. Published by the author, Nashville, Tenn.

[44]Ames, A. Cyclophoria. *American Journal of Physiological Optics*, Vol. VII, pp. 3–38, 1926.

[45]Verhoeff, F. Torsion of eyes. *American Journal of Physiological Optics*, Vol. VII, pp. 39–57, 1926; *Johns Hopkins Bulletin*, May, 1899.

[46]Sheard, Charles. Cyclophoria. *American Journal of Physiological Optics*, Vol. V, p. 457, 1924; *ibid*, Vol. VI, p. 65, 1925.

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placing prism and the Maddox multiple rod. Others believe that the eye which sees the streak as horizontal is normal in so far as cyclophoria is concerned, and that cyclophoria is exhibited by the eye which observes the streak lacking horizontality and parallelicity. The test may be made monocularly by carrying out the procedure with each eye in turn.

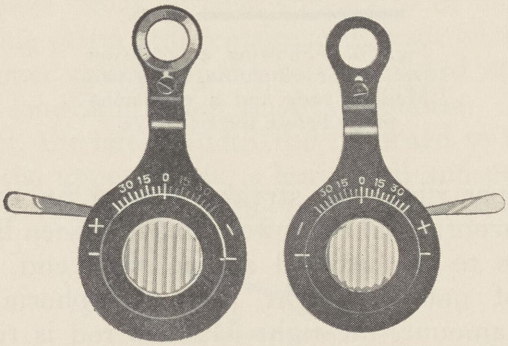

Fig. 55. Maddox rods: axes vertical

In conducting this test it is well to have the examination room darkened and to use a fairly brilliant small source of light as a fixation target, care being taken to remove all extraneous light sources. The patient's ametropic correction is to be inserted in the proper dials in the Phoroptor, and the instrument is to be in horizontal balance and correctly adjusted for the interpupillary distance.

Place in operative position the two Maddox rods with axes vertical and before one eye, say the *right* one, the 6Δ, base up, displacing prism. The patient should then see two separate and distinct ribbons of light, one above the other. If there is an appreciable lateral imbalance or a vertical imbalance of a character to be corrected by the 6Δ prism, base up, swing the rotary prism unit before the eye under test (*e.g.* the right one) and insert such an amount of prismatic element as to cause the two lines to be well sep-

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arated vertically and to lie, approximately, the one directly under each other. The upper ribbon or bar of light will be seen by the left eye and the lower one by the right eye. If the two streaks lie in the same horizontal plane and are parallel, there is no manifest cyclophoria.

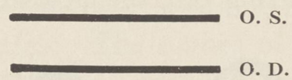

Fig. 56. Showing a condition free from cyclophoria, using two Maddox rods and a displacing prism before the right eye

If the upper ribbon or streak, as seen by the left eye, remains horizontal and the lower streak, as seen by the right eye, appears to tilt upward at the right end, there is a condition of manifest right plus cyclophoria. To ascertain the amount, the right Maddox rod is turned temporally until the lower streak becomes horizontal and parallel to the upper streak. The graduated scale engraved upon the mounting carrying the Maddox rod will show the amount of cyclophoria.

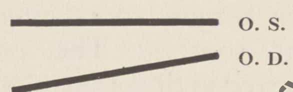

Fig. 57. Right plus cyclophoria, using two Maddox rods and a displacing prism before the right eye

If the lower streak of light appears to dip downward at the right end and the upper line remains horizontal, there is a condition of manifest right minus cyclophoria. To ascertain the amount, rotate the Maddox rod nasally until the lower streak is parallel to the upper one. The graduated scale will show the amount of right minus cyclophoria.

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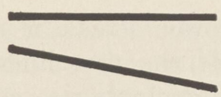

Fig. 58. Right minus cyclophoria, using two Maddox rods and a displacing prism before the right eye

If the lower streak of light appears to be horizontal (the 6Δ displacing prism still remaining in front of the right eye) and the upper streak appears to tip upward at its left end, there is a condition of left plus cyclophoria. To ascertain the amount, the left Maddox rod is turned to the temporal side until the upper streak is horizontal and parallel to the lower ribbon (Fig. 59). If the lower streak of light remains

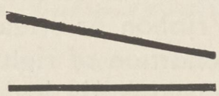

Fig. 59. Left plus cyclophoria, using two Maddox rods and a displacing prism before the right eye

horizontal while the upper one seems to tilt upward toward the right side, a condition of left minus cyclophoria exists (Fig.60). To measure its amount, the left Maddox rod is turned nasally until the two streaks are horizontal and parallel.

Fig. 60. Left minus cyclophoria, using two Maddox rods and a displacing prism before the right eye

With the two Maddox rods vertical and the 6Δ displacing prism before the *left eye*, the patient will again see two ribbons of light. The upper one is seen by the right eye,

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while the image of the lower streak is received upon the retina of the left eye. If the two lines are parallel and horizontal, no apparent cyclophoria exists (Fig. 61). If

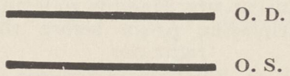

Fig. 61. A condition free from cyclophoria, using two Maddox rods and a displacing prism before the left eye

the lower ribbon appears to tilt downward toward the right end, there is a condition of left plus cyclophoria (Fig. 62). Left minus cyclophoria is indicated by such findings as those shown in Fig. 63. If the lower streak of light appears horizontal and the upper ribbon or streak tilts upward at its right end, there is a condition of right plus cyclophoria (Fig. 64). Right minus cyclophoria is depicted in Fig. 65,

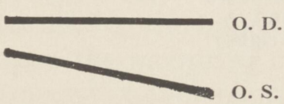

Fig. 62. Left plus cyclophoria, using two Maddox rods and a displacing prism before the left eye

Fig. 63. Left minus cyclophoria, using two Maddox rods and a displacing prism before the left eye

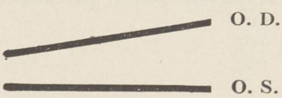

Fig. 64. Right plus cyclophoria, using two Maddox rods and a displacing prism before the left eye

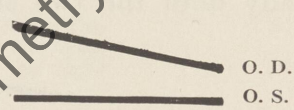

Fig. 65. Right minus cyclophoria, using two Maddox rods and a displacing prism before the left eye

the amount of the torsional tendency being measured by the number of degrees the right Maddox rod needs to be turned nasally to produce a condition of horizontalism and parallelicity of streaks.

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Since both double Maddox rods are of clear uncolored glass, the red glass color supplied with the Phoroptor may be employed advantageously in making any or all of these tests. By placing one of the red filters before the eye carrying the 6Δ displacing prism, the streak of light seen by that eye is distinguished readily from the ribbon or streak of light seen by its mate.

TESTS FOR CYCLOPHORIA AT THE READING DISTANCE

Tests upon the tendencies of the vertical axes of the eye to lose parallelism with the median plane of the head or to rotate on the antero-posterior axis or axes, as the case may be, may be tested at the patient's customary reading or

● **Read these Words Letter by Letter**

Fig. 66. Line of type to be used for testing cyclophoria at the reading distance. Or a single, finely ruled line may be used

working distance by the same general procedures as have been outlined for fixation at twenty feet or more. The test-object, however, should be a single ruled line, say two inches in length, or a single row of letters as shown in Fig. 66. The card carrying the line or row of letters should be inserted in the holder upon the reading rod of the Phoroptor. The writer believes that the instrument should be so angled before the patient's face as to bring the line or row of letters in about the same position as reading matter, such as the newspaper, is commonly held. Others disagree with this notion and would make these tests in the usual straight-away position. At any rate, the examiner may exercise his preference: the instrument permits of adjustment to allow for any procedure desired.

There is no necessity of further repetition of the character of the tests or of the indication for plus or minus cyclophoria of either the right or left eye (or of both eyes), since they have

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been presented in detail in the preceding paragraphs. Obviously the Maddox rods are not used since the ruled lines or row of letters upon the fixation card replaces the streak produced by the Maddox rod when a source of light is used at twenty feet.

Some practitioners prefer to use a Maddox double prism before one eye. This produces two images—an upper and a lower one—in the eye before which it is placed; the other eye sees a third line situated between the two lines produced by the Maddox double prism. Both eyes must be tested separately, the one under test being that before which the double prism is *not* placed, *i. e.*, the eye seeing the central line.[47] The tests should also be made with and without correcting cylindrical lenses (distance or presbyopic corrections being used) especially if the correcting cylinders are placed at oblique axes, as is frequently the case if cyclophoria is present.

With regard to tests on cyclophoria Thorington[48] writes: "This test is usually made at 13 or 18 inches from the patient's eyes. A narrow straight black line is placed horizontally on a white card as the fixing object at the distance indicated. A Maddox double prism is placed before the left eye so that the bases bisect the pupil horizontally, and this eye then sees two parallel horizontal lines if its oblique muscles are in a standard condition. The right eye sees

● **Read these Words Letter by Letter** O. S.

● **Read these Words Letter by Letter** O. D.

● **Read these Words Letter by Letter** O. S.

Fig. 67. Orthophoria of oblique muscles, using the Maddox double prism before the left eye

[47]Laurance, Lionel. *Visual Optics*, London, 1927.

[48]Thorington, James. *Refraction of the Eye and Methods of Estimating the Refraction*. P. Blakiston's Son & Co., p. 261, 1916.

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but one line between the two lines seen by the left eye. The right eye is the one being tested and the position of the

● Read these Words Letter by Letter O. S.

● Read these Words Letter by Letter O. D.

● Read these Words Letter by Letter O. S.

Fig. 68. Insufficiency of left superior oblique, using the Maddox double prism before the left eye

● Read these Words Letter by Letter O. S.

● Read these Words Letter by Letter O. D.

● Read these Words Letter by Letter O. S.

Fig. 69. Insufficiency of right superior oblique

● Read these Words Letter by Letter O. D.

● Read these Words Letter by Letter O. S.

● Read these Words Letter by Letter O. D.

Fig. 70. Insufficiency of the left inferior oblique

● Read these Words Letter by Letter O. D.

● Read these Words Letter by Letter O. S.

● Read these Words Letter by Letter O. D.

Fig. 71. Insufficiency of the right inferior oblique

middle line furnishes the diagnosis. If the left eye is to be tested, then the Maddox double prism must be placed before the right eye."

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If cyclophoria of any appreciable degree exists—since many believe that a plus cyclophoria of 1° to 2° is normal—the only refractive procedure which has been advocated with a considerable degree of experimental proof is that proposed by Steele and elaborated upon by Savage.[49] The Steele rule as applied to plus cylinders is as follows:
"In cases in which the axes of the proper convex cylinders for the two eyes diverge, place the cylinders in those positions which will give the axes the greatest divergence permitted by the tests: and in those cases in which the axes converge, place them at the points which give them the greatest convergence permitted by the tests."

Savage comments further on this rule: "The Steele rule for placing the axes of plus cylinders is applicable only when these axes are within 45 degrees of the vertical. Above the 45 degree point the shifting should be from the vertical; below the 45 degree point the shifting should be from the horizontal. In every case of oblique astigmatism with the meridians of greatest curvature diverging or converging when there is cyclophoria the axes of plus cylinders should be displaced toward the center of the quadrants in which they are found, and the axes of minus cylinders should be shifted from the center of the quadrants in which they are found."

[49]Savage, G. C. *Oblique Astigmatism.* An essay contributed to the *American Encyclopedia of Ophthalmology*, Vol. XI. Cleveland Press, 1917.

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CHAPTER VII

THE DUCTION TESTS

THE RECTI MUSCLES

VERTICAL tests measure the ability of a pair of eyes to maintain binocular single vision. They are not necessarily indicative of the strengths of the recti or oblique muscles: they are fundamentally quantitative analyses of the delivery of innervation from the appropriate centers.[50] "Duction is fusional and not volitional and is under the control of the fusion centers operating in the interests of binocular single vision. If, in an eye, the image is displaced into any part of its fusional domain, the fusion faculty will move the macula to it when possible."[51]

As Savage[52] says: "When an image is displaced by a prism to any point within the field of fusion of an eye, while the image in the other eye remains upon the macula, an effort at fusion will be made, and if the muscle that must respond is sufficiently strong, fusion will at once take place, caused by such a rotation as will bring the macula under the displaced image. When the image is thrown by a stronger prism, entirely outside of the field of fusion, the guiding sensation, which seems to reside in this area only, will not call on any muscle to move the eye for the purpose of fusion. The nasal limit of this retinal area, as measured by a prism in front of the eye, is 8Δ; the temporal limit, 25Δ; the upper limit, 3Δ; and the lower limit, 3Δ. The line drawn through these four points marks the entire boundary of the field. These may be considered as the normal size of *fusion area.*" This size of normal fusion area is applicable, however, to

[50]Banister, J. M. Functional anomalies of the ocular muscles: their nature, their detection and their significance. (Four papers.) *American Journal of Physiological Optics*, Vol. V, 1925.

[51]Sheard, Charles. *Dynamic Ocular Tests.*

[52]Savage, G. C. *Ocular Myology.*

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fixation at 20 feet only; the size of fusion area differs for the lateral recti muscles considerably from that given by Savage when fixation is at 13 inches, for example. This, in and of itself, throws some doubt upon Savage's statement that "the guiding sensation" resides in the area only which

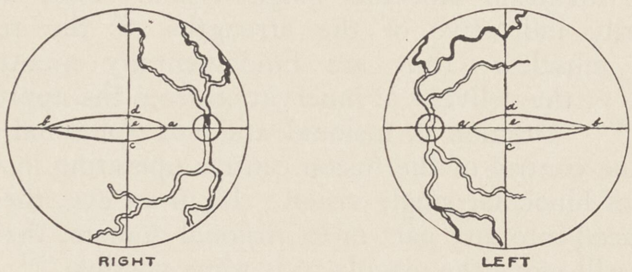

Fig. 72. Fusion fields. (After Savage)

he has specified. Be this as it may, the normal field of binocular fusion for distant fixation is the peculiar kite-shaped area in each retina shown in Fig. 72 (taken from Savage).

The duction tests of the recti muscles are based on Savage's physiologic principle, which teaches that when a prism is placed before the eye with its base located accurately in, out, up or down, *only that rectus muscle lying beneath the apex of the prism is stimulated to action*, all other muscles of both eyes remaining passive in so far as the effect of the prism is concerned.

By utilizing this fundamental principle, the independent contractile power or range of dissociated action of each rectus muscle may be measured accurately and its value relatively compared with the corresponding rectus muscle of the other eye. Hence, in many cases, the origin of the imbalance may be determined very definitely.

The following table on the ductions of the various recti

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muscles will be of assistance to those who are not veterans in the science and art of ocular myology.

Table of Ductions

Duction	*Muscle Involved*	*Position of Ducting Prism*	*Normal Value at 20 Feet*
Abduction	Externus	Base in	6–8△
Adduction	Internus	Base out	16–25△
Superduction	Superior	Base down	2–3△
Infraduction	Inferior	Base up	2–3△

Without entering into too much detail, it should be pointed out that the *total* prism used should be placed with its apex over the rectus muscle which is under test. Right abduction and left abduction are, therefore, obtained by placing the prism, base in, before the right eye and then, in turn, before the left eye, all prismatic power being removed from the eye which is *not* under test. In this manner the examiner is enabled to obtain *monocular* duction tests. If the prismatic power is divided between the eyes, the test is a binocular one and does not give data which have the significance of those obtained by monocular procedures.

METHODS OF MAKING DUCTION TESTS

The duction test, like the monocular test of the coördination of the recti muscles, should be conducted in a dark room with the aid of a luminous test-object, such as the Greek cross (or a single illuminated letter or, again, a very small spot of light) located five or six meters distant and in direct vertical and horizontal alignment with the Phoroptor.

An accurate and well centered correction for the patient's

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ametropia, if any, should be in place during these tests. Such tests, like all others upon ocular functions, are more reliable if the vision is 15/20 or better.

ADDUCTION TEST

To test the right adduction, or independent contractile power of the internal rectus muscle of the right eye, variable

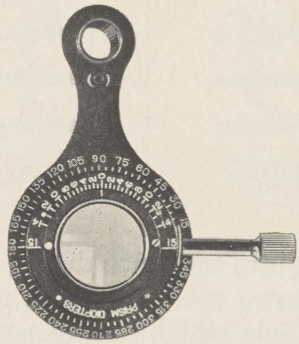

Fig. 73. Double rotary prism unit, zero graduation mark vertical

prismatic power with base out, or towards the temporal side, should be employed. A double rotary prism unit should therefore be placed before the right eye with zero graduation vertical (Fig. 73) and the indicator rotated slowly outward from zero until the object is caused to double in appearance in the horizontal plane, at which point a reading from the prism scale should be taken. Since the range of the double rotary prism units of the Phoroptor is but 15Δ, and as the adduction requirements may be in excess of that figure, it is good practice to rotate the 15Δ prism, base out, in the rear dial (Fig. 74) into position before the eye under test and to then turn the rotary prism, also before the same eye, quite rapidly nasally (hence inserting prismatic power, base in) until a single fixation source is observed. Then slowly reduce the prismatic power, base in, in the rotary prism unit

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and continue rotating it temporally until insuperable diplopia occurs. The algebraic sum of the 15Δ fixed prism, base out, and the prismatic value in the rotary unit will give the value of the adduction. The 15Δ fixed prism, base out, when used

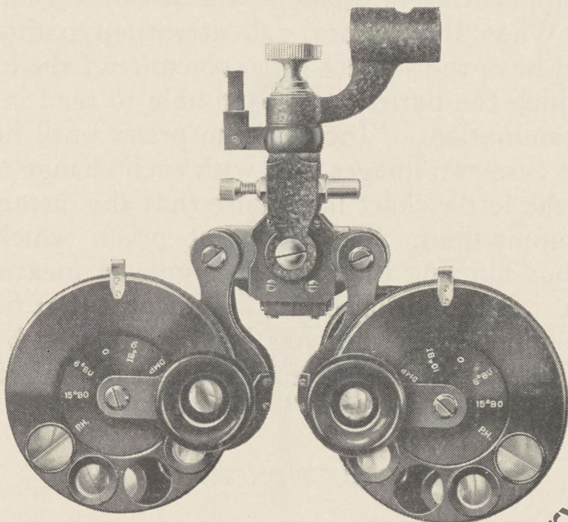

Fig. 74. Phoroptor with 15^{Δ}, base out, in position before the eye

in conjunction with the double rotary prism unit, affords a continuous range from zero to 30 prism diopters, base out, with the added advantage of open scale readings for the full prism range.

The adduction test should be repeated several times in order to obtain the highest prism value with base out which can be accepted without diplopia, or double vision. The prism value thus obtained will indicate the adduction (right adduction, if right eye is under test) and should be so recorded.

There are those who may assume the position taken by Needles[53], who writes: "It is important that a test for

[53]Needles, W. B. *Ocular Muscles.* Course No. 3. Department of Education, American Optometric Association, 1919.

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adduction should not involve the act of convergence. This may be made in a simple manner. . . . . Proceed to place prisms before the eyes, base out, beginning with moderate powers and increasing until the subject reports diplopia. The first appearance of diplopia will be quickly followed by fusion." When this occurs, call attention to the chart of letters and have the subject endeavor to read the lowest line of type which the patient has been able to read in the subjective examination. "Increase the prism until he finds it difficult to fuse two images, but with each change of prisms, revert to the letter chart to be sure that the distance vision remains unimpaired. The strongest prism which he can fuse without blurring the test types gives a measure of the adduction. If the vision blurs, it indicates that his accommodation is not static, but has been stimulated by convergence. The prism must be weakened just to the point where he can read the normal type."

ABDUCTION TEST

To determine the right abduction, or independent contractile power of the external rectus muscle of the eye, variable prismatic value, base in, or towards the nasal side, should be employed. The double rotary prism should remain, therefore, in the same relative position as before (Fig. 73) but the indicator in this instance should be rotated in the opposite direction, or inward from zero. This inward rotation of the indicator should be continued until the object appears to double in the horizontal meridian, when a reading from the prism scale of the rotary unit should be taken. This test should be repeated several times. The average of these readings (excluding the initial one, which serves only as an explanatory trial) gives a measure of the right abduction and is so recorded.

The adduction and abduction are rated normally at about three to one, or 24 to 8 prism diopters respectively. This,

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however, may vary considerably in different instances, but the three-to-one rule ordinarily applies when normalcy exists. Sthenic and asthenic conditions should be carefully differentiated, since they give valuable data on the general tonus of the innervational centers (*i. e.* third and sixth nerves) of the recti muscles.

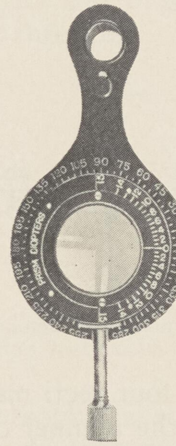

Fig. 75. Double rotary prism unit, zero graduation mark horizontal

SUPERDUCTION AND INFRADUCTION TESTS

To test the right superduction, or independent contractile power of the superior rectus, variable prismatic power, base down, should be employed. The double rotary prism should be placed before the eye with its zero graduation horizontal (Fig. 75) and the prism indicator rotated slowly downward from zero until the object appears to double in the vertical plane. This will usually equal 2 to 3 prism diopters, but may fall as low as zero or rise as high as 4 to 6 prism diopters in some instances. Extreme care should be exercised when making this test, as it is very sensitive due to the range of independent action of the vertical recti muscles.

To determine the right subduction or infraduction, which is the independent contractile power of the inferior rectus

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muscle of the right eye, the same procedure should be followed as in obtaining the right superduction, except that prismatic power, base up, is slowly turned before the eye using the double rotary prism unit. This test also should be repeated several times, as it is likewise sensitive and must be conducted carefully if an accurate estimate of the subduction is to be obtained.

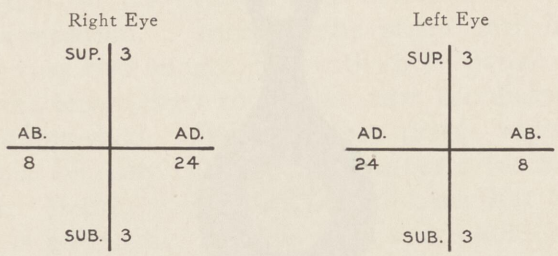

Fig. 76. Illustrating normal and sthenic ductions in both eyes

When the tests of the four recti muscles of the right eye have been completed in the manner described, similar tests should be made for each of the four recti muscles of the left eye and the results of the tests accurately recorded.

After testing each rectus muscle of each eye separately, a comparison of the results obtained indicates the relative strengths of the innervations to the various muscles or possibly strengths of the muscles themselves and, in the event of an imbalance, aids in determining which muscle or muscles of either eye, or both eyes, as the case may be, are lacking in tone. Muscle exercise, prisms or operative procedure may then be prescribed, after these data, in addition to further information obtained by version tests and other corroborative evidence are secured and analyzed.

VALUE OF DUCTION TESTS

Figure 76 illustrates a condition of normal ductions in both eyes and in strength (*i. e.* sthenic).

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To further illustrate the value of the duction tests with fixation at 20 feet, take the case of lateral imbalance (exophoria) in which the following data have been obtained: Right adduction 24Δ, right abduction 8Δ; left adduction 18Δ with an abduction of 12Δ. A comparison of these figures indicates that the condition of exophoria, as disclosed by coördination tests, is a case of left exophoria arising from a manifestly weak left internus.

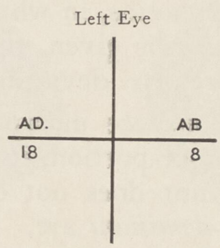

Fig. 77. Illustrating ductions in a case of left exophoria

Likewise in cases of esophoria, hyperphoria or hypophoria (cataphoria), definite duction measurements, made upon each eye independently, will usually indicate which muscle or muscles, as the case may be, are relatively too strong or too weak as regards either strengths of muscles or innervations, and consequently which of the recti muscles are involved in the imbalance.

THE DOMINANT EYE AND DUCTION TESTS

Sheard[54] presents ideas which are somewhat at variance with those statements which have been given with reference to the necessity of taking duction tests upon the lateral recti of both eyes. He believes that the data upon the non-dominant eye, which is not accustomed normally to fixate, are to be expected to differ from data obtained upon the

[54]Sheard, Charles. The dominant eye—its significance in strabismus, muscular imbalance and duction tests. *American Journal of Physiological Optics*, Vol. IV, p. 294, 1923.

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dominant or normally fixating eye. He says: "The ratio of abduction to adduction cannot be expected to be the same in the two eyes if a dominant eye exists."

By way of conclusion and résumé Sheard writes: "In making duction tests, especially upon the lateral muscles, it would appear to be sufficient to make these duction tests upon the *non-dominant* eye. In vertical directions, it is best to take them upon each eye in turn.

"In cases of tropias or phorias, in which prismatic exercises or like treatments are to be given, the whole of the prism should be placed before the deviating or non-fixing eye.

"If prismatic corrections are incorporated in the glasses prescribed, then the major portion, if not the total in cases in which the full amount does not exceed 2Δ, should be placed before the *non-dominant eye*. If 1Δ to 2Δ, base in, out, up or down, are to be incorporated in lenses, they should be worn before the non-dominant eye. In other words, interfere to the least extent possible with the dominant eye in its function of straight-away fixation."

DUCTION TESTS OF THE OBLIQUE MUSCLES

The range of independent action of the oblique muscles may be measured in a dark room by means of a procedure known as the cycloduction test.

To make this test, place a Maddox multiple white rod in operative position before each eye with the axis of each rod horizontal (Fig. 78) and employ a luminous test object not over 10 mm in diameter, located five or six meters distant in the dark room and in direct vertical and horizontal alignment with the Phoroptor.

Should the patient be either ametropic or heterophoric, or both, a suitable correction for the same should be placed before the eyes, because any action of the recti muscles is undesirable during the making of these tests.

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The observer should see but one fairly broad band of light (Fig. 79). To measure the duction range of the superior oblique of the right eye, the rod on the corresponding side of the instrument should be rotated slowly and steadily

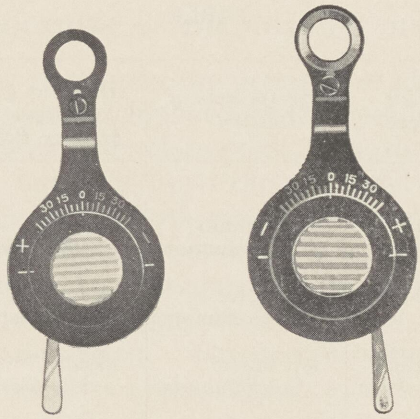

Fig. 78. Maddox rods, indicators vertical (axes horizontal) for testing the duction powers of the oblique muscles

downward at its *nasal* end until the band of light begins to break or assumes the appearance of a somewhat distorted

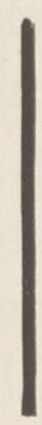

Fig. 79. Broad band of light seen in making tests on cycloductions

Fig. 80. To measure the duction range of the superior oblique of the right eye, the rod on the corresponding side of the Phoroptor should be rotated until the band of light begins to break as indicated

Fig. 81. To measure the duction range of the right inferior oblique, rotate the rod on the corresponding side until the band of light breaks as indicated

letter X (Fig. 80), whereupon the position of the indicator with respect to the inner scale will denote the degree of right minus cycloduction.

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The accompanying table will be of assistance in ascertaining the oblique muscle involved and what is measured by specified rotations of the double Maddox rods:

TABLE

Eye	*Muscle (oblique)*	*Specification of Duction*	*Direction of Rotation Maddox Rod*	*Value*
Right	superior	right minus cycloduction	nasally downward	The average lies between 5 and 15 degrees of arc, although it may fall as low as 2 to 3 degrees or rise as high as 25 degrees
	inferior	right plus cycloduction	temporally downward	
Left	superior	left minus cycloduction	nasally downward	
	inferior	left plus cycloduction	temporally downward	

After taking the right minus cycloduction and after returning the rod to its former position for a moment, with the axis horizontal and the indicator at zero, it may be rotated downward at the temporal end until the vertical band of light breaks in the opposite direction as shown in Fig. 81., whereupon the position of the indicator with respect to the outer scale will denote the duction range of the right plus cycloduction.

The plus and minus cycloductions of the left eye may be taken in like manner. The Maddox rods employed should both be white, otherwise the full fusion effort of the oblique muscles will not be obtained and in consequence no reliable data gathered.

The subject of cyclophoria and cycloduction has received

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very complete treatment at the hands of Stevens[55] and of Savage[56] and reference should be made to their writings as well as to those whose names are given in the list of references appended to this chapter.

CYCLODUCTIONS AT THE READING DISTANCE

Not only may tests upon the presence or absence of right or left plus or minus cyclophoria of the eyes be made at the reading distance or other close point, as outlined in the preceding chapter, but tests upon the strengths of the oblique muscles of either eye, or both eyes, may also be made at the reading distance. A small source of light, conveniently enclosed in a suitably diaphragmed chamber which may be attached to and moved along the reading rod, will serve as a satisfactory fixation point. The details of the procedure of obtaining cycloductions at close distances is the same as those which have been outlined in other portions of this chapter.

EXERCISING THE RECTI MUSCLES

The recti muscles, especially the lateral ones, may often be exercised effectively for the correction of imbalances through the employment of the double rotary prism units.

Should the duction tests of the recti muscles made in a case of exophoria show, for example, a right adduction of 24Δ, with an abduction of 8Δ, while the left adduction is 16Δ, and the corresponding abduction is 14Δ, we believe that the imbalance may be attributed to the inherent weakness of the left internus or possibly spasticity of the left externus.[57]

[55]Stevens, George T. *The Motor Apparatus of the Eyes.* F. A. Davis & Company, Philadelphia.

[56]Savage, G. C. *Ophthalmic Myology and Ophthalmic Neuro-Myology.* McQuiddy Printing Company, Nashville, Tenn.

[57]Kletzky, David. Prescribing prisms in ocular practice. *American Journal of Physiological Optics*, Vol. IV, 1923 to Vol. VII, 1926. (This is a valuable series of articles which was terminated by the author's death. Earlier papers are to be found over a period of years in the *Optical Journal and Review.*)

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To exercise the weak left internal rectus muscle independently, a double rotary prism unit should be placed before the left eye only, with zero graduation vertical and the attention of the observer directed with both eyes to a suitable luminous object or letter—preferably a Greek cross—located five or six meters distant in a dark room devoid of extraneous light sources.

An alternately increasing and decreasing prismatic value should then be applied with the base opposite the muscle to be exercised. Therefore, in this instance, the prism pinion should be turned so as to cause a slow and steady rotation of the indicator outward from zero until diplopia occurs, in which event the prismatic power should be reduced and the exercise repeated. This alternate rotation of the indicator outward from zero and back again will cause the muscle to contract steadily as the prismatic element is increased and then in turn relax as the prismatic value is decreased, thereby producing a natural and effective exercise, which, as is evident, may be given independently to any rectus muscle of either eye through the use of correctly placed prisms.

If, after exercising a muscle or muscles, as the case may be, in this way four or five minutes a day for several days, a stronger prism can be accepted than at first, the range of exercise may be correspondingly lengthened and the practice continued until a permanent balance and erradication of the imbalance is obtained.

To illustrate these points, take the data given by Thorington[58]: Static refraction, O. U. +0.50 D. S. ⊃ +0.37 cyl. axis 90° ; V = 20/15. Adduction and abduction (binocular test), 12Δ each, with an exophoria of 4Δ. The patient gave a history of seeing double several times a day. Has had frequent occipital headaches. Headaches occur when using her eyes, but they soon pass away after resting her eyes.

[58]Thorington, James. *Methods of Refraction*, p. 348. P. Blakiston's Son & Co., 1910.

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With the correction, adduction is 14Δ and abduction is 12Δ, with 3Δ of exophoria at 6 meters and 15Δ of exophoria at 13 meters. "This patient was given prism exercises for more than two months, and, finally after the adduction reached 30Δ and the abduction was 10Δ and 3Δ of esophoria were obtained, the prism exercises were stopped, and the patient told to report promptly if any discomfort arose at any time, and to wear her glasses (O. U. +0.37 D. cyl. ax. 90°) constantly. At the present time this patient would receive the fixation exercise and not the long treatment with prisms."

The experiences of most refractionists are to the effect that muscle exercises are of chief value in exophoric conditions. In esophoria, the indications are to increase the convex findings or decrease the concave findings as much as possible, resorting to prisms and prismatic exercises as a last resource from the optical standpoint. Vertical imbalances do not respond readily if at all to exercising except possibly in young persons. As a general rule it is found that both superduction and infraduction may be increased, but the inherent vertical imbalance generally persists. As a result, therefore, many authorities disparage the use of prisms (with occasional exceptions) other than in conditions of vertical imbalances. In fact, no less an authority than Maddox[59] writes: "If lateral deviations are complicated by hyperphoria (*i. e.* vertical imbalance) correct the vertical deviation first and the lateral will take care of itself." Prentice[60] is in full accord with this opinion.

There are, therefore, a multiplicity of ideas and writings upon the subject of the use of prismatic and other exercises in the case of imbalances of the recti muscles as well as a

[59]Maddox, E. E. Heterophoria. *American Journal of Physiological Optics*, Vol. III, p. 25, 1922.

[60]Prentice, Charles F. Lateral adaptability of the extrinsic ocular muscles in ametropia. *American Journal of Physiological Optics*, Vol. III, p. 109, 1922.

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greater variation in the conditions under which prisms are or are not to be prescribed. One of the most recent books on muscle exercises is by Robinson[61]; he gives complete details as to his methods of giving such exercises.

EXERCISE OF THE OBLIQUE MUSCLES

The oblique muscles may be individually exercised by placing a Maddox graduated multiple white rod before each eye, with indicators vertical or axes of rods horizontal and employing a luminous test-object about 10 mm in diameter located five or six meters distant. This is the same set-up of the Phoroptor as described elsewhere on the duction tests of the oblique muscles.

To exercise the superior oblique of the right eye, for example, the index of the rod on the corresponding side of the instrument should be rotated slowly and steadily inward from zero to a point on the scale one or two degrees short of the point at which the single vertical band of light will break into the form of the letter X, and then returned to zero. The alternate rotation of the rod through this arc will cause the muscle to contract steadily as the indicator departs from zero and then, in turn, to relax as it approaches zero, thereby producing a natural and effective exercise. As is evident, this same method of exercising the inferior oblique may be applied by rotating the indicator in the opposite direction, or outward from the zero point and then back again to zero.

The obliques of the left eye may be exercised by using the Maddox rod already placed in operative position in the Phoroptor.

Savage recommends exercising with cylindrical lenses as well as permanently throwing some small burden upon the weak oblique muscle (or oblique muscles) by displacing the

[61]Robinson, Samuel H. *Oculo-Prism Treatment*, or how to make ocular muscle tests and give practical muscle exercises. Professional Press, Chicago, Ill., 1925.

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axes of the cylinders used. However, since Maddox rods are, in the last analysis, simply cylindrical lenses of large dioptric value, it is obvious that exercising with cylinders is the same in essentials as exercising with Maddox rods.

RÉSUMÉ OF DUCTION TESTS AND MUSCLE EXERCISES

Since the procedure for exercising the ocular muscles is the same as is employed in the duction tests, this résumé of points serves equally well for both topics.

1 Before performing these tests or exercises, clear the instrument of everything except the correcting lenses, if such are to be used.

2 *Internal recti:* To exercise the internal rectus muscle of the right eye, or to get its adductive power, place a double rotary prism unit with its zero point vertical before the right eye and slowly rotate the indicator temporally (thus placing prism, base out, before the eye) until two images of the fixation object appear. The indicator then shows the amount of right adduction.

3 Repeat the test with the double rotary prism unit before the left eye. The indicator shows the amount of left adduction.

4 *External recti:* Place the rotary prism with its axis vertical before the right eye and slowly rotate the indicator nasally until double images appear. The indicator shows the amount of right abduction.

5 Repeat the test with the rotary prism before the left eye; the indicator shows the amount of left abduction.

6 *Superior rectus:* To test the superior rectus of the right eye, place the rotary prism with its axis horizontal before the right eye and slowly rotate the indicator downward until double images appear. The indicator shows the amount of right superduction.

7 Repeat the test with the prism before the left eye. The indicator gives a measure of the left superduction.

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8 *Inferior rectus:* Place the rotary prism unit before the right eye with its zero horizontal and gradually rotate the prism indicator upward until double images appear: the indicator registers the amount of right subduction or infraduction.

9 Repeat with the rotary prism unit before the left eye, and the indicator will show the amount of left subduction, or infraduction.

10 *Oblique muscles:* Place a Maddox rod before each eye, axis horizontal, and with the indicator at zero.

11 Gradually rotate the rod before the right eye nasally downward until the single vertical line breaks, forming an acute shaped X. This measures the amount of right minus cycloduction and tests the right superior oblique.

12 Repeat the process, rotating the left rod downward nasally until the line or streak of light breaks. The indicator shows the amount of left minus cycloduction and measures the power of the left superior oblique.

13 Rotate the right rod downward temporally until the line breaks. The indicator shows the amount of right plus cycloduction and measures the power of the right inferior oblique.

14 Repeat the test with the left eye, rotating the rod downward temporally until the line breaks. The indicator gives the amount of left plus cycloduction and measures the strength of the left inferior oblique.

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CHAPTER VIII

THE ACCOMMODATIVE CONVERGENCE AND FUSION CONVERGENCE TESTS AT THE READING DISTANCE

THE FUNCTION OF CONVERGENCE

IN DISTANT vision there are normally only two grades of convergence, the *tonic* and *reflex*, as shown in Fig. 82. In near vision, however, there is an intermediate grade, or the *accommodative*, as shown in Fig. 83. When reading the

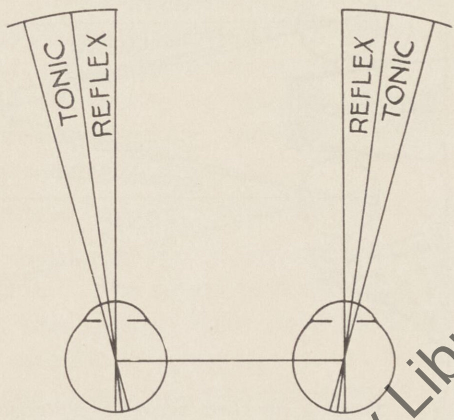

Fig. 82. Showing tonic and reflex (fusional) convergences with fixation at distance

newspaper or looking at close distances, therefore, all three types of convergence may be demanded. Or, again, it is possible that the tonicity tests at 20 feet show orthophoria and that similar tests at the reading distance evidence orthophoria, in which event there would be evidence that the whole of the convergence in reading or other close work comes through or in accompaniment with the act of accommodation, hence the convergence would be wholly *accommodative*. Or again, no tonic errors may exist at twenty

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feet and yet, at thirteen inches, with an interpupillary distance of 60 mm, demanding a total convergence of 18Δ at the 13 inch (33 cm.) point for binocular single vision, there may be an exophoria of 18Δ. If, under subsequent test, with no prisms or dissociating devices before the patient's

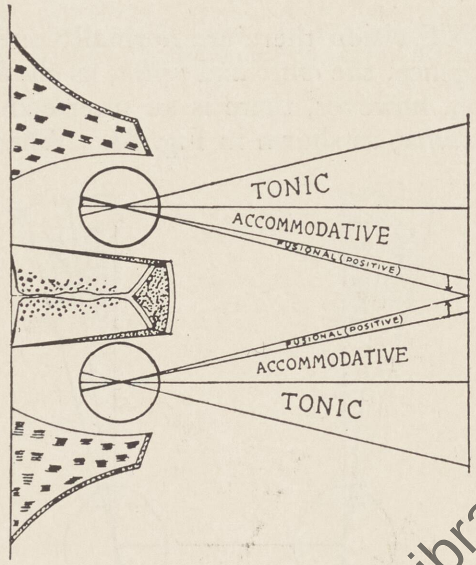

Fig. 83. Showing the three types of convergence—tonic, accommodative and fusional—usually involved in binocular single vision at the reading point.

eyes, the subject under examination has binocular single vision, we have evidence that the convergence necessary for binocular single vision at the 13 inch point comes through stimulation of the convergence fusional centers. Such a condition is known as *fusional* convergence.

In the normal condition of affairs, however, binocular single vision is enjoyed through a combination of accommodative and fusional convergences. If one eye is covered while the other is fixing a near object, the occluded eye will,

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in the majority of persons who are neither hypermetropic nor presbyopic, deviate outwards 3° to 4°.[62] This condition of affairs was first noted by von Graefe who detected, in many cases of myopia, "muscular insufficiency", as he named it. Maddox was one of the first, if not the first, to devise a scale for the measurement of what may be called the "exophoria in near vision". By his methods he demonstrated that a small amount of exophoria at the reading distance was a frequent physiological condition. The exophoria revealed by various methods of procedure to be described in detail in the succeeding paragraphs shows that the association of convergence with accommodation is not complete centrally, so that a supplementary action is needed to supply the deficiency and, since the involuntary motive for this action is afforded by the desire to fuse two images into one, the proportion of convergence thus kept up may be called *fusion convergence.*

PHYSIOLOGICAL OR ACCOMMODATIVE EXOPHORIA

There has arisen in the literature the expression *physiological exophoria.* The latest and most carefully conducted researches on this subject have been those by Sheard[63], and Weymouth[64] and his colleagues. From these researches, as well as from the earlier and pioneer work of Howe, Theobald, Duane, Maddox and others, we may conclude:

1 Seventy-five per cent of persons who possess normal vision, either with or without correcting lenses, and who possess no vertical imbalances greater than 1Δ, no lateral imbalances greater than 2Δ, no anisometropia and no pathological lesions, show 2Δ –7Δ of accommodative exophoria at the thirteen inch point.

[62]Maddox, E. E. *The Clinical Use of Prisms*, p. 160. John Wright & Co., Bristol.

[63]Sheard, Charles. On accommodative exophoria. *American Journal of Physiological Optics*, Vol. I, p. 234, 1920.

[64]Weymouth, Frank W., Brust, P. R. and Gobar, F. H. Ocular muscle balance at the reading point. *American Journal of Physiological Optics*, Vol. VI, p. 184, 1925.

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2 It seems desirable, therefore, to take as the standard at the ordinary reading distance of about a foot a condition of exophoria of from 4 to 5 prism dioptries; this deficit being supplied through the fusion centers (hence fusion convergence) in the act of binocular single vision at thirteen inches. This normal exophoria of about 5Δ is quite frequently referred to as "physiological exophoria".

3 It should be emphasized that this condition is not a true exophoria, as the term was originally defined by Stevens, or even an insufficiency of convergence. In the absence of a fusion stimulus, the convergence normally induced by accommodation is less than that required for single vision.

ACCOMMODATIVE AND FUSION CONVERGENCES

Sheard[65], writing on accommodative or physiological exophoria, says: "Many confuse that which has been designated as *accommodative convergence* with *physiological exophoria*, failing to appreciate the fact that the accommodative convergence is an indication only of the innervation to convergence induced by or taking place in accompaniment with the actual or attempted functioning of accommodation. Accommodative convergence, normally present, is a definite, positive quantity, whereas physiological exophoria, when present, is a deficit or a negative quantity and is an indication or measure of the amount of innervational convergence which must be supplied through the appropriate fusional centers (or fusion faculties) in order that binocular single vision may exist. Such an exophoria is not, in any sense of the expression, an insufficiency of the convergence nor of the internal recti. Such an exophoria is an expression of the fact that normally binocular single vision is not accomplished centrally in conjunction with accommodation or, in other words, the whole of the

[65]Sheard, Charles. Accommodative or physiological exophoria. *American Journal of Physiological Optics*, Vol. VI, p. 580, 1925.

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convergence is not accommodative in character. When such an exophoria exists, the deficit in the total convergence necessary for binocular single vision at any given fixation distance must come from another source, the fusional centers."

The accommodative convergence tests at about a third of a meter are of considerable importance in the consideration of whether or not a pair of eyes can see singly, comfortably and efficiently when close work of various types is attempted. Such tests determine whether all the convergence that is needed in order to obtain and maintain binocular single vision at the reading distance is associated with the act of accommodation, whether it is supplied wholly through the fusional centers, or whether it is a combination of both accommodative and fusional convergences.

It is impossible to enter into a detailed discussion of these matters. Reference should be made to two volumes by Sheard entitled *Dynamic Ocular Tests* and *Dynamic Skiametry*.*

TECHNIC OF ACCOMMODATIVE CONVERGENCE TESTS

With the improved Phoroptor the accommodative convergence relationships may be ascertained in three ways or by using the following:

1 The Maddox double prism
2 The 6Δ fixed displacing prism
3 The Maddox rod

THE MADDOX DOUBLE PRISM PROCEDURE

The best form of chart is a card, which can be inserted in the movable holder on the reading rod of the Phoroptor and at any desired distance, carrying a single small black circle or dot and a line of type. This is illustrated in Fig. 84.

● **Read these Words Letter by Letter**

Fig. 84. Showing a single dot and row of letters to be used in accommodative convergence tests

*While both of these valuable books are out of print at present, a revision and re-issue are to be forthcoming shortly.

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The test may be made with the Maddox double prism over either eye. In general, however, if there is a dominant eye, the Maddox double prism or other dissociating device should be placed over the non-dominant or non-fixating eye. Ordinarily, therefore, the prism will be placed before the left eye. With the card carrying the dot and line of type placed at the reading distance (or about thirteen inches), the Maddox double prism before the left eye and the right eye occluded, the patient will see two lines of type or rows of letters. Care should be exercised to see that the common base of the double prism is in such a position that it approximately bisects the pupil of the patient's eye and that it is so placed that the two dots appear to be in a plumb or vertical line.

While the patient is observing the two lines of type—which should be seen equally distinct in normal conditions—with the left eye, the right eye is uncovered, when a third line should be seen lying between the other two previously observed by the left eye only. If three lines are not seen, it is more than likely that the eye carrying the Maddox double prism is not receiving the double images. This can be ascertained very readily. If the double images or two lines of type are observed by the one eye and the third or intermediate line is not observed, it is indicative of either mablyopia or a considerable degree of exophoria (exotropia), esophoria (esotropia) or of a fairly high vertical imbalance. Simple occlusion tests, in which the eyes are alternately covered with a screen and then uncovered, with the eyes attempting to fix a close object, such as a pencil, will disclose generally redress movements of such a character as to indicate the condition of ocular coördination at the reading or other close point.

If there is neither accommodative exophoria nor esophoria (indicating a condition of accommodative overconvergence), the three black dots will appear to lie directly under each

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other or in vertical alignment. Figure 85 illustrates a condition of no accommodative exophoria or esophoria at the reading or other close fixation distance.

● **Read these Words Letter by Letter** O. S.

● **Read these Words Letter by Letter** O. D

● **Read these Words Letter by Letter** O. S.

Fig. 85. Showing a condition of no accommodative exophoria at thirteen inches, using the Maddox double prism before the left eye

If the middle black dot and line are to the left of the upper and lower dots and lines, the Maddox double prism being before the left eye, there is an accommodative exophoria present and the amount of prism, base in, which, when placed before the left eye, brings the three dots into vertical alignment is a measure of the exophoria. To measure the amount of this exophoria, place the rotary prism unit before the left eye with its zero graduation vertical. If the 15Δ limit provided in the one rotary prism unit is not sufficient, place the second prism unit in operative position before the other eye and finish the examination. Figure 86 illustrates

● **Read these Words Letter by Letter** O. S.

● **Read these Words Letter by Letter** O. D.

● **Read these Words Letter by Letter** O. S.

Fig. 86. Showing a condition of accommodative exophoria at thirteen inches using a Maddox double prism before the left eye

a condition of accommodative exophoria when the Maddox double prism is placed before the left eye.

If the dot and line seen by the right eye, the Maddox double prism being placed before the left one, are centered

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vertically between the upper and lower lines but occupy a position to the right of the upper and lower dots, as shown in Fig. 87, there is a condition of accommodative overconvergence or esophoria. This can be measured by the amount of prism, base out, inserted in the rotary prism unit or units to vertically align the three black dots.

● **Read these Words Letter by Letter** O. S.

● **Read these Words Letter by Letter** O. D.

● **Read these Words Letter by Letter** O. S.

Fig. 87. Showing a condition of accommodative esophoria at thirteen inches using a Maddox double prism before the left eye

Attention should now be directed to the condition of the vertical recti muscles.

If so-called accommodative orthophoria exists, or if the accommodative exophoria or esophoria has been corrected by means of prisms, base in or out as the case may be, the central black dot and line should lie midway between the upper and lower lines if there is a condition of vertical orthophoria at close fixation distances.

If the middle dot and line lie nearer the top row of letters, then the right eye is turning downward or the left eye is

● **Read these Words Letter by Letter** O. S.

● **Read these Words Letter by Letter** O. D.

● **Read these Words Letter by Letter** O. S.

Fig. 88. Showing a condition of left hyperphoria at thirteen inches, with the Maddox double prism before the left eye

turning upward (left hyperphoria) and the amount of prism, base down, over the left eye, or prism, base up, over the right eye, that will bring the middle dot and line exactly

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midway between the upper and lower lines is a measure of the vertical imbalance. To obtain a measurement of the vertical imbalance, place the rotary prism unit in operative position with its zero graduation horizontal. The relative positions of the images in a case of left hyperphoria are shown in Fig. 88.

● **Read these Words Letter by Letter** O. S.

● **Read these Words Letter by Letter** O. D.

● **Read these Words Letter by Letter** O. S.

Fig. 89. Showing a condition of right hyperphoria at thirteen inches, with the Maddox double prism before the left eye

If the second dot and line are nearer the bottom line, then the left eye is turning downward or the right eye is turning upward (right hyperphoria) and the amount of prism, base down, before the right eye or base up before the left eye which will bring the middle dot and line exactly midway between the upper and lower lines of type is a measure of the right hyperphoria. This is illustrated in Fig. 89.

In all of these tests, as well as in similar procedures, the patient's ametropic corrections should be in position before the eyes. If presbyopia is present, the reading addition should also be incorporated.

THE FIXED DISPLACING PRISM PROCEDURE

The 6Δ fixed displacing prism, with its base up, may be used as an alternative method of investigating the accommodative convergence relationship. As in the case of the Maddox double prism, it is preferable to place the 6Δ, base up, displacing prism before the non-dominant eye and to measure the esophoria or exophoria which may be disclosed by the use of the rotary prism unit, also placed before the same eye as carries the displacing prism.

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If there is no accommodative exophoria or esophoria, the dots and lines of type will be vertically aligned as in Fig. 90.

● **Read these Words Letter by Letter** O. D.

● **Read these Words Letter by Letter** O. S.

Fig. 90. Showing a condition of no accommodative exophoria at thirteen inches, using a 6^{Δ} fixed displacing prism before the left eye

If the upper dot and line are to the left of the lower dot and line (the fixed prism being in operative position before the left eye) there is a condition of accommodative exophoria and the amount of prism, base in, before one or both eyes (preferably before the eye carrying the displacing

● **Read these Words Letter by Letter** O. D.

● **Read these Words Letter by Letter** O. S.

Fig. 91. Showing a condition of accommodative exophoria at thirteen inches, with a 6^{Δ} fixed displacing prism before the left eye

prism), needed to cause vertical alignment of the dots is a measure of the exophoria. The appearance of the images as seen in a condition of accommodative exophoria, using the 6Δ fixed displacing prism before the left eye, is shown in Fig. 91.

If the upper dot and line of type are to the right of the lower dot and line of type, as is shown in Fig. 92, with the fixed displacing prism before the left eye, there is a condition

● **Read these Words Letter by Letter** O. D.

● **Read these Words Letter by Letter** O. S.

Fig. 92. Showing a condition of accommodative esophoria at thirteen inches, using a 6^{Δ} fixed displacing prism before the left eye

of accommodative esophoria or overconvergence. The amount of prism, base out, before one or both eyes necessary to produce vertical alignment of the dots is a measure of the accommodative esophoria.

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THE MADDOX ROD METHOD

A third method of obtaining information regarding the accommodative convergence is through the use of a Maddox rod and a suitable small source of light placed or held by the patient at the desired distance. This method, however, suffers inaccuracy by reason of the fact that a light, per se, does not offer the same stimulus to accommodative action as does a row of letters which must be read

O. S.

O. D.

Fig. 93. Lateral orthophoria at thirteen inches using the Maddox rod with axis horizontal before the left eye

letter by letter. The fact that there is this difference in stimulation to the accommodative activities probably accounts for much of the variation in ocular practice and explains many of the divergent views held by various writers and competent examiners.[66] This method, therefore, is not to be recommended except in cases of low visual acuity and in suppressed or intermittent vision in one eye. In such conditions it is often possible to obtain information on the condition of the accommodative convergence by the use of the Maddox rod, when other methods would fail.

The technic of procedure is to make use of the bare light of the retinoscope or ophthalmoscope. With the Maddox rod in position before either eye, or preferably before the non-dominant one, and with its axis horizontal, the patient will see a vertical ribbon of light as well as the natural source of light. If the ribbon of light cuts through the light source proper, there is no accommodative exophoria. (Fig. 93.)

[66]Sheard, Charles. A subjective method of skiascopy. *Journal of Optical Society of America*, Vol. XII, p. 79, 1926, and also *American Journal of Physiological Optics*, Vol. VII, p. 76, 1926.

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If the ribbon of light is to the right of the fixation source (Maddox rod before the left eye), there is a condition of accommodative exophoria, as shown in Fig. 94, and the amount of prism, base in, before one or both eyes necessary to bring

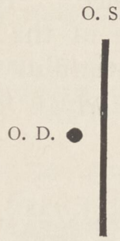

Fig. 94. Accommodative exophoria at thirteen inches using the Maddox rod with axis horizontal before the left eye

the streak and light into exact superposition measures the exophoria at the near point of test.

If the streak of light is to the left of the luminous source of fixation, there is a condition of accommodative overconvergence or accommodative esophoria (Fig. 95), and the

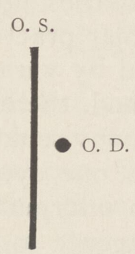

Fig. 95. Accommodative esophoria at thirteen inches using the Maddox rod with axis horizontal before the left eye

amount of prism, base out, which will cause the ribbon of light to pass through the center of the fixation spot of light, shows the amount of the esophoria.

This method of testing is generally accepted as being of greater value in measuring the vertical rather than the lateral imbalance. As a matter of experience it is said that this method suffers in its accuracy from the same inherent errors as does the test when applied with a fixation source at twenty feet. These sources of error have been discussed in Chapter VI, to which reference should be made by those

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interested. Furthermore, since the accommodative stimulus and action should be as constant as is possible and since experimentation has demonstrated that a luminous source or point of fixation does not serve as a very efficient or certain stimulus to accommodation, it follows that the data obtained by this method are not as dependable as are the

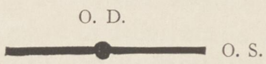

Fig. 96. Vertical orthophoria at thirteen inches using the Maddox rod, axis vertical, before the left eye

data obtained through the use of a dot and line of type as the fixation object. Neither can it be expected that the data obtained by the use of the Maddox rod and a luminous source of fixation will agree with the findings by the other methods described in this chapter.

As previously stated, however, the Maddox rod and fixation light serve very well in examinations of the coördination of the vertical recti muscles either at distant or near points of fixation.

If the ribbon of light, which is caused to appear in a horizontal direction by placing the Maddox rod with its axis in a vertical position before either eye, passes directly through the source of light (Fig. 96), there is vertical orthophoria.

If the streak of light is above the source of light (Maddox rod before the left eye), then the left eye turns downward or the right eye turns upward, hence affording evidence of a condition of right hyperphoria. The amount of prism, base up, before the left eye or base down before the right eye

Fig. 97. Right hyperphoria with Maddox rod, axis vertical, before the left eye

which causes superposition of the streak and light, indicates the amount of right hyperphoria. This condition of affairs is diagrammed in Fig. 97.

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On the other hand, if the ribbon of light is below the fixation source (Maddox rod before the left eye), as is shown in Fig. 98, the left eye turns upward or the right eye turns downward (left hyperphoria) and the amount of prism,

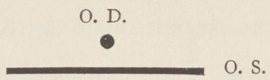

Fig. 98. Left hyperphoria with Maddox rod, axis vertical, before the left eye

base up, before the right eye or prism, base down, before the left eye which brings the two into superposition is a measure of the left hyperphoria.

BRIEF DISCUSSION OF ACCOMMODATIVE CONVERGENCE TESTS

Accommodative convergence tests at the customary reading distance are very important in considerations relative to the ease and comfort with which a pair of eyes enjoys binocular single vision when close work is attempted. These tests indicate very definitely whether all of the convergence that is necessary for binocular single vision at the reading or other close point is associated with the act of accommodation, *i. e.* central, whether it is supplied wholly by the fusional centers, or whether it is a combination of the two sources acting together in a certain proportionate ratio.

Normally it is believed that the act of binocular single vision is accomplished most efficiently when the accommodative convergence is from two-thirds to three-fourths of the total amount needed for binocular single vision, the remaining one-third to one-fourth being supplied by the positive fusional centers. Therefore, as a result, if this standard is accepted, an *accommodative* or *physiological* exophoria of about 4Δ to 6Δ at the customary reading distance of about a foot is to be taken as indicative of normalcy. From the standpoint of accommodative convergence, therefore, an exophoria at thirteen inches of from 4Δ to 6Δ is to be expected if the best innervational conditions exist. It

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follows then that so-called accommodative orthophoria at a close fixation point is, in reality, indicative of accommodative overconvergence or esophoria of from 4Δ to 6Δ. And again, an apparent accommodative esophoria of 5Δ is actually to be considered as being from 9Δ to 11Δ. Such considerations as these will modify the examiner's procedure in the prescribing of lenses, especially as to the giving or withholding of full plus or full minus corrections.

But the data on the accommodative convergence alone are not sufficient to solve the whole of the problem of ocular economy and efficiency when the eyes are engaged in binocular single vision. If the total convergence necessary for binocular single vision is not obtained centrally, *i. e.* wholly in accompaniment with the act of accommodation, then the deficit must be supplied from other sources, namely the *fusional* centers, if binocular single vision is obtained. This brings us to a brief consideration of the reserve fusional convergence tests or, as they might equally well be called, duction tests at the selected near point of fixation.

RESERVE FUSION CONVERGENCE TESTS

After the accommodative convergence tests have been made and recorded as actually found, *i. e.* no imbalance, exophoria or esophoria as the case may be, the examiner should proceed to make tests upon the positive and negative reserve fusional convergences at the customary reading distance. In other words, he should obtain the adduction and abduction as well as the superduction and subduction at the close working distance selected.

The positive reserve fusion convergence corresponds, therefore, to the adduction test at twenty feet. A vertical row of letters or line of type provides an excellent fixational target for two reasons. In the first place, it stimulates a maximum of accommodation and thereby relieves the appropriate fusion centers from the burden of providing an

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undue amount of activity in order that binocular single vision may be obtained initially. Furthermore, it serves as an indicator of the fact that the accommodation is not continuing stationary and constant if the row or line of letters remains single but become considerably blurred or indistinct in appearance. Some portion of this indistinctness

KEEP THIS ROW OF LETTERS SINGLE

Fig. 99. Test card to be used in determining the reserve fusional convergence at thirteen inches

may be attributed, without doubt, to the metamorphopsia produced by fairly large prismatic powers which act as ducting agents in these tests.

With proper corrections of the patient's ametropia in the batteries of lenses and cylinders which form a part of the Phoroptor and, in the case of presbyopia, the inclusion of the necessary reading additions, and with the instrument properly adjusted for the interpupillary distance when engaged in reading, the rotary prism units and the two 15Δ prism,

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base out, contained in the rear dials of the instrument are swung into operative position before the patient's eyes and manipulated in the following manner: The indicators of the two rotary prism units are set initially at zero and then rapidly rotated so that each places before the appropriate eye 15Δ prism, base in. As a result the 15Δ prisms, base out, inserted in position in each of the back dials so as to come in front of the eyes, are neutralized by the 15Δ prism, base in, inserted in each of the rotary prism units.

To obtain the positive fusion reserve, slowly reduce the power of the prisms in the rotary units before either one eye or both eyes. The amount of reduction of power in the rotary units indicates the amount of prismatic power, base out, before the eyes. The subject under examination is directed to keep the vertical row of letters single as long as possible and to report diplopia or blurring of the letters as soon as either (or both) occurs. Slowly reducing the prisms, base in, in the rotary prism units until the indicators are again at the zero points, leaves the two 15Δ prisms, base out (in the rear dials), effectively operative before the eyes, or a total of 30Δ prism, base out. If singleness and distinctness of vision still persists, additional prismatic power, base out, may be introduced by turning the elements of the double rotary prism units in such a direction as to insert prisms, base out, before either one or both eyes. By proceeding to the limit of the rotary units it is possible to place a total of 60Δ before the eyes. However, this is rarely necessary and if such is found to be the case it is highly probable that diplopia has occurred without the knowledge of the patient. If this should be the case it will very likely be discovered upon repetition. The positive reserve fusion convergence normally ranges, at the thirteen-inch fixation distance, from about 20Δ to 30Δ.

The negative fusion reserve convergence, which corresponds to the abduction test at twenty feet, is obtained by

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the use of the rotary prism units placed before either eye or both eyes and inserting prismatic power, base in, until diplopia ensues. If more than 30Δ are necessary, one or both of the two 10Δ, base in, fixed displacing prisms may be swung into operative position in the back dials. The negative fusion reserve normally ranges from 18Δ to 24Δ.

To illustrate the significance of these tests we are taking illustrative material from the book *Dynamic Ocular Tests* by Charles Sheard.

Case 1 No muscular imbalances with a fixation distance of 20 feet, hence no tonic errors. The accommodative convergence tests indicated an exophoria of 16Δ. (If the interpupillary distance is 60 mm, then 18Δ are demanded for binocular single vision at 13 inches, the distance of the near fixation test-chart.) We have evidence, therefore, that the accommodative convergence is 2Δ (*i. e.* 18Δ − 16Δ). The positive fusion centers must supply the innervation necessary to provide binocular single vision. The positive fusion convergence reserve was found to be 15Δ. In this case, therefore, the demand upon the positive fusion centers was greater than the reserve. Such a set of conditions cannot exist and permit of continuous and comfortable binocular single vision. The remedies, from the optical standpoint only, are: (a) prismatic or other extra-ocular exercises, (b) the incorporation of prisms, base in, in the corrective glasses and (c) a combination of both.

Case 2 Tonicity tests at 20 feet, the patient wearing O. U. +1.50 D. S. with V = 20/20 monocularly, indicated 5Δ of esophoria. Accommodative convergence tests at 13 inches showed 5Δ of esophoria, leading us to the conclusion that the accommodative convergence was central and that the tonic error of 5Δ esophoria carried over into the close fixation tests. The positive fusion convergence reserve was 30Δ; the negative fusion reserve (or abduction) was 10Δ, all tests being made at 13 inches. Obviously

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the drain will not be upon the positive fusion centers but upon the negative convergence centers, which show a total fusional amplitude of 15Δ, of which 5Δ are demanded in the interests of binocular single vision. This demand of 5Δ out of a total of 15Δ can be normally supplied and probably without discomfort. But the data indicate that the accommodative convergence is excessive and this fact, together with the initial esophoria of 5Δ, call attention to the probable need of further suppression of the accommodation or relaxation of an accommodative spasm.

FUSIONAL RESERVES OF THE RECTI MUSCLES

A horizontal line or row of letters, similar to that shown in Fig. 84, should be used in making tests upon the fusional powers of the vertical recti muscles at the reading distance. As there are four muscles which must be considered it is desirable to obtain the following:

1 Right supra reserve
2 Right infra reserve
3 Left supra reserve
4 Left infra reserve

Such tests follow very naturally after the determination of the positive and negative reserve convergences at the reading distance.

The right supra reserve is obtained through the use of the rotary prism unit placed before the right eye and inserting prism, base down, before this eye until diplopia ensues.

The right infra reserve is obtained by turning prism, base up, into the right rotary prism unit until singleness of vision is no longer obtained.

The left supra reserve and the left infra reserve are obtained in a manner analogous to that given for these reserves of the right eye; the rotary prism is placed before the left eye, however.

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Normally the supra reserve should be 2Δ to 3Δ in each eye at the usual reading distance of about thirteen inches; the infra reserves are usually a trifle higher or from 3Δ to 4Δ.

If there is a genuine vertical imbalance at close points, it is generally possible to determine the muscle or innervational source at fault through the duction data obtained at close points. Again, it is possible that the error will be disclosed as a relative one only, in which event the right supra reserve will correspond to and practically agree with the left infra reserve, and in turn the right infra reserve should correspond to the left supra reserve. For example, if the data are:

Left Eye	*Right Eye*
Supra reserve, 1Δ	Supra reserve, 2Δ
Infra reserve, 4Δ	Infra reserve, 3Δ

and these consistently check, it may be inferred that the left superior rectus muscle or its innervation is at fault. If prismatic power is incorporated in the final correcting lenses it should be inserted before the left eye. If the data are:

Left Eye	*Right Eye*
Supra reserve, 5Δ	Supra reserve, 1Δ
Infra reserve, 1Δ	Infra reserve, 4Δ

we may conclude that there is a relative weakness of the right superior rectus and left inferior rectus and their innervations. In that case, prisms may be incorporated in the correcting lenses and divided between the two eyes or, if there is a dominant eye, it may be incorporated wholly before the non-dominant eye if the prismatic element is of a low value.

The subject of accommodative and fusional convergences and the various tests upon the lateral and vertical recti muscles at close fixation points are too intricate to present in the compass of a single chapter. The importance of these tests, however, cannot be over-emphasized and they should become a portion of the routine of examination of each and every pair of eyes.

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CHAPTER IX

SOME POINTS ON PRESBYOPIA AND ACCOMMODATIVE RESERVES

DONDERS[67] stated the very important principle that "the accommodation can be maintained only for a distance at which, in reference to the negative part, the positive part of the relative range of the accommodation is tolerably great". And Howe[68] writes: "In our studies of the conditions of the muscles we shall find the most important and apparently the most frequent anomalies are those which involve the ciliary muscle. Therefore, even in routine examinations, and at the first visit, it is desirable to determine whether the action of that muscle is normal, or excessive, or insufficient. At least a general idea as to this power of the ciliary is shown . . . simply by placing a minus three diopter glass before each eye and asking the patient to read again the distant test type. I have learned to regard this as one of our most important tests. For if, after the ciliary muscles have had a minute or two in which to adjust themselves, the person can still read as well as before, then we know at once, at least in a general way, that there is no imperfection in the power of the ciliary muscle, apart from convergence."

These and other quotations which might be cited clearly indicate the necessity of routine examinations on the amplitudes of accommodation. The importance of data upon the monocular and binocular amplitudes and ranges of accommodation has been emphasized in recent years by Duane.[69]

[67]Donders, Franz C. *Accommodation and Refraction of the Eye.* The New Sydenham Society, 1864.

[68]Howe, Lucien. *The Muscles of the Eye*, Vol. I, p. 399. G. P. Putnam's Sons, New York.

[69]Duane, Alexander. Monocular and binocular accommodation. *American Journal of Ophthalmology*, Vol. V, p. 865, 1922; also articles in *Archives of Ophthalmology*, Vol. LI, p. 396, 1922; *ibid*, p. 396, 1922.

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CILIARY RESERVES

The determination of the ciliary reserve has an important bearing in the following conditions:

1 In the determination of the necessity for the correction of genuine presbyopia.

2 To determine sub-normal accommodation, which may be found at any period or age below the normally presbyopic age or what may be called "premature presbyopia".

3 To determine, in myopia, whether the full distance corrections should be given for constant or general wear and, if not, what deductions should be made if one pair of glasses only is prescribed, or again if two pairs of glasses or bifocals are to be given.

METHODS FOR THE DETERMINATION OF THE AMPLITUDES OF ACCOMMODATION

The far-front may be defined as the greatest distance at which an eye has maximal sharpness of vision, or it is the most remote point (*punctum remotum*) at which the eye, in a state of rest, has maximal acuity of vision. On the other hand, the near point (*punctum proximum*) is the nearest point to the eye at which it has distinct vision and the crystalline lens of the eye is then in a condition of greatest convexity or maximal refraction. The amplitude of accommodation, or its power, is the difference between the refraction of an eye in a state of rest (or adapted for its far point) and in a condition of maximal refraction (or adapted for its near point). For an emmetropic eye, there is no accommodation used for infinity and, if the near point is at 10 centimeters, the amplitude or power of accommodation is 10 D.

The determination of the monocular and binocular ranges and amplitudes of accommodation is of importance as a routine test and must of necessity be made in cases of presbyopia.

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The term *accommodative reserve*, however, implies that the accommodative demands for any given distance of fixation are met and that there is, in addition, a reserve power or residuum of accommodative action. The determination of the near point by various methods devised by Donders, Jackson, Duane and others gives a measurement of the maximal value of the accommodative power and thereby prognosticates, to a certain extent, whether or not a given amount of accommodation (*e. g.* three diopters, as demanded in reading at thirteen inches) can be maintained without fatigue and other reflex symptoms.

For the determination of accommodative power and accommodative reserves there are four fundamental methods:

1 Near point measurements.

2 Use of concave lenses, with visual fixation at twenty feet.

3 Use of concave lenses, with visual fixation at the customary reading distance.

4 Objective (skiametric) determinations of the near point.

I. SUBJECTIVE NEAR POINT DETERMINATIONS

Duane[70] employed in his investigations an excellent test object—a fine black line, about a quarter of an inch in length, engraved on a suitable white card, which could be moved along a modified Prince rule (or the reading rod of Phoroptor would serve nicely). When the line begins to blur, its distance from the anterior focal point of the eye is read off the scale on the rule or Phoroptor rod. From the hundreds of determinations of near points made by Duane, he prepared the following table:

[70]Duane, Alexander. *American Journal of Ophthalmology*, Vol. V, p. 865, 1922.

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TABLE SHOWING MAXIMAL, MINIMAL AND AVERAGE MONOCULAR AMPLITUDES OF ACCOMMODATION IN RELATION TO AGE

Age (Years)	*Maximal Accommodation*	*Minimal Accommodation*	*Mean*
10	15.5 D.	11 D.	13.5 D.
15	14.5	10	12.3
20	13.4	9	11.1
25	12.2	7.8	9.9
30	10.8	6.5	8.7
35	9.3	5.2	7.3
40	7.9	3.4	5.8
45	5.9	1.9	3.6
50	3.2	1.0	1.9
55	1.9	0.8	1.3
60	1.7	0.7	1.2
65	1.6	0.6	1.1

Duane further investigated or compared the monocular with the binocular amplitudes of accommodation. His results are given in the following table:

TABLE SHOWING A COMPARISION OF THE MONOCULAR AND BINOCULAR AMPLITUDES OF ACCOMMODATION

Age (Years)	*Excess of Binocular Over Monocular Amplitudes*	
	Extreme Excess in Diopters	*Usual Excess in Diopters*
8 to 15	0 to 6	1 to 2
16 to 34	0 to 3	0.5 to 1.5
35 to 40	0 to 2.5	0 to 1.5
40 to 45	0 to 2	Usually not over 1 D.
45 to 50	0 to 1.4	Usually below 1 D.

We may conclude, therefore, that it is to be expected that:

1 The binocular amplitude of accommodation will be regularly higher than the monocular value.

2 The binocular exceeds the monocular by amounts varying from 0.25 D. to 1 D.

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3 When the monocular value exceeds that of the binocular, we may be sure of muscular imbalances.

4 The accommodative surplus in binocular vision is apparently due to a convergence action which induces an extra accommodative effort which is impossible when one is not converging binocularly. In monocular accommodation there is evidently a certain degree of inertia which must be situated in the ciliary muscle, or which we may call the *physiological accommodation*.

5 At any rate, the added range and increased clearness in binocular vision constitute a very real advantage, especially in presbyopia.

II. CONCAVE LENSES WITH DISTANT FIXATION

If in a case of emmetropia, or a pair of eyes rendered as nearly normal or standard in vision as possible, *concave* lenses are added monocularly (the other eye being occluded) until the visual acuity is reduced, the examiner obtains a measure of the *positive* accommodative reserve for the point of fixation specified. The *negative* accommodative reserve, or negative relative accommodation, is obtained through the use of *convex* lenses. Obviously, if the refraction has been properly executed with fixation at 20 feet, the negative accommodative reserve will not exist at that distance. The same is not true with reference to the positive accommodative reserve with fixation at 20 feet.

There are several disadvantages to this method of procedure:

1 The visual acuity is considerably diminished by the concave lenses, which reduce the sizes of the retinal images normally obtained.

2 The standard of "distinct vision at distance" is indefinite.

3 It is difficult to induce an eye to put forth its maximal

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effort of accommodation when looking at distance, for accommodation is not naturally invited.

If the examiner desires to pursue this method, however, in his tests he can do so very quickly and easily with the improved Phoroptor, for lenticular changes can be made as rapidly as desired.

III. CONCAVE LENSES AT THE READING POINT

It is said that "any ocular function should be investigated under conditions of activity or quiescence which conform to the philosophy of the particular phase of its activity under consideration".[71] The normal reading distance is about a foot from the eyes: it is logical, therefore, to determine its reserve with respect to the point at which the reserve is vital.

The method is easily carried out in practice. The test should be made monocularly and before each eye should be placed the distance correction, particularly the cylindrical element. The spherical element should be the maximal convex or minimal concave lens which, either alone or in combination with the cylinder, if such is demanded, affords an acuity of 20/20 or as nearly the normal standard as can be obtained. In cases of presbyopia, the presbyopic corrections should be worn. Use the reading chart or card furnished with the Phoroptor and, in general, direct the patient to read the No. 2 Jaeger type (V = 0.50 D.) placed at thirteen inches. If this type is read, it may be concluded that the ciliary muscle has exerted three diopters of accommodative action or, at least, produced three diopters of equivalent refractive change if normally acting. Minus spheres, beginning in general with −0.50 diopter glass, should then be inserted before the eye until the maximal minus lens has been used through which the No. 2 Jaeger (V =0.50 D.) is barely or difficultly read. The available amplitude of ac-

[71]Sheard, Charles. *Dynamic Ocular Tests*, p. 90 and *Dynamic Skiametry*, p. 49. Cleveland Press, 1920.

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commodation is, therefore, the sum of the three diopters exerted by the accommodative mechanism in order to read at thirteen inches, plus the amount of concave lens power overcome and expressed as a positive quantity. For example, if a pair of eyes having V = 20/20 at 20 feet and wearing proper corrective lenses can read the fine print at 13 inches through a −5.00 D. S., then the amplitude of accommodation at 13 inches, as measured by this method, is 8 diopters. The *positive accommodative reserve* is, in this case, 5 diopters. The *negative accommodative reserve* can be found, if desired, through the use of convex lens power inserted before the eye until the patient is unable to read the fine print at the thirteen-inch point. If this should amount to a +2.00 D. S., then the negative accommodative reserve would be recorded as 2 diopters.

Such tests can be very conveniently and quickly carried out with the improved Phoroptor. Convex lens power can be readily decreased by turning the lenses in the dials *nasally* (for positive accommodative reserve) and increased by turning them temporally (for negative accommodative reserve). A similar set of manipulations can be made in the case of myopia, in which concave or minus corrective lenses are worn.

As an illustrative case, suppose the distance correction to be O. U. +5.00 D. S. The No. 2 Jaeger type is read at 13 inches. Slowly reducing the convex lens values, it is found that the fine type is barely readable through +1.00 D. S. in the case of each eye tested monocularly. The amplitude of accommodation at the thirteen-inch fixation point is, therefore, 7 diopters (the sum of the three diopters normally exerted plus the difference between 5 D. lens and 1 D. lens, or 4 D.), and the positive accommodative reserve is 4 diopters.

In cases of presbyopia, the same procedure and interpretation are to be followed. In a presbyopic condition of fair amount the fine type on the reading card is not readable

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without the addition of extra convex lens power. Suppose the addition is O. U. +2.00 D. S. With this correction the patient reads the No. 2 Jaeger type (or the closest to this in cases of considerably reduced acuity as evidenced by tests at 20 feet); the reading correction is then slowly reduced, say by steps of 0.25 D. S. If the subject under test can barely read the properly selected print on the reading chart through the addition of +1.00 D. S., the examiner has evidence of the fact that the amplitude of accommodation is 4 diopters and that the positive accommodative reserve is 1 diopter. Obviously, if he prescribes in such a case a presbyopic addition of +2.00 D. S., he leaves 2 diopters of accommodation operative and artificially supplies with the reading correction of +2.00 D. S. the other 2 diopters. Or in other words, he allows one-half of the total accommodative resources at the thirteen-inch reading distance to be used and the other half to be held in reserve.[72]

We append a table of amplitudes of accommodation as determined by various investigators.

TABLE OF AMPLITUDES OF ACCOMMODATION

Age (Years)	*Donders (Near Point)*	*Duane (Near Point) Average*	*Jackson (Concave Lenses Accommodation Associated with Convergence)*	*Sheard (Concave Lenses. Monocular Test. Object at 13 in.)*
10	14 D.	13.5 D.	14 D.	12 D.
15	12	12.5	12	11
20	10	11.5	10	9
25	8.5	10.5	9	7.5
30	7.0	8.9	8	6.5
35	5.5	7.3	7	5
40	4.5	5.9	5.5	3.75
45	3.5	3.7	4	2.75
50	2.5	2.0	2.5	——
55	1.75	1.3	1.55	——
60	1.00	1.0	0.5	——

[72]Sheard, Charles. *Ocular Accommodation*. Course No. 14. Department of Education, American Optometric Association. Also article on "Some points in handling cases of presbyopia and subnormal accommodation," *American Journal of Physiological Optics*, Vol. IV, p. 202, 1923.

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IV. OBJECTIVE METHOD FOR THE DETERMINATION OF THE NEAR POINT

This method, which is a skiametric procedure, has already been described under the heading of Dynamic Skiametry, Chapter V, to which the reader is referred.

Full and complete details cannot be given in the compass of this book on the significance of various findings upon the values of the positive and negative accommodative reserves. Reference should be made to the citations given in the footnotes and to the list appended to this chapter.

PRESBYOPIA

There is no exact age limit at which presbyopia makes its appearance. The advent of presbyopia is controlled by the character of the ametropia and the physiological or pathological condition of the eyes.

According to Thorington[73], presbyopia may be described in several different ways, according to the cause, *i. e.*

1 Old sight.

2 The condition of the eye in which the punctum proximum has receded to such a distance that near vision (close work) is impossible without the use of convex lenses.

3 The condition of the eye in which the lens fibers have become more or less sclerotic, and, as a consequence, the lens loses some of its inherent quality of becoming more convex during contraction of the ciliary muscle.

4 The condition of the eye in which the power of the ciliary muscle has become weakened.

5 The condition of the eye in which the power of accommodation is diminished at the same time that the lens fibers become sclerotic.

Fundamentally, therefore, presbyopia is a condition of the eye in which close work, such as reading, is impossible with-

[73]Thorington, James. *Methods of Refraction*, p. 364. P. Blakiston's Son & Co.

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out the aid of convex lenses, on account of either lenticular changes or innervational weaknesses, or possibly both. If such changes occur at or about the age of 45 years they are considered normal; if they occur in young people or children, they are spoken of as being conditions of *subnormal accommodation.*

PRESBYOPIC NEAR POINTS

The near point and power of accommodation in a non-pathological emmetropic eye, or a healthy eye made emmetropic by the addition of proper corrective lenses for distant vision, is somewhat as follows for various ages:

Age (Years)	*Near Point (cm.)*	*Power of Accommodation (Diopters)*
40	22	4.50
45	28	3.50
50	40	2.50
55	55	1.75
60	100	1.00
65	133	0.75
70	400	0.25
75	infinity	0.00

Any disease which will interfere with the nutrition of the lens must affect its power of accommodation. The most common ailments that tend to do this are influenza, la grippe, Bright's disease, diabetes, rheumatism, gout, lithiasis, syphilis, tuberculosis, and so forth.

It is of importance to determine not only the near point but also the far point with the presbyopic findings supplied to the person under examination. Obviously the difference between the reading near- and far- points gives the range of accommodation. Thorington, in his book on *Methods of Refraction,* supplies the following table for emmetropic eyes:

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Years	*Addition (Diopters)*	*Near Point (cm.)*	*Far Point (cm.)*	*Range (cm.)*
45	+1.00	22	100	78
50	+2.00	22	50	28
55	+2.50	23	40	17
60	+3.00	25	33	8
65	+3.00	27	33	6
70	+3.00	30	33	3
75	+3.00	33	33	0

PRACTICAL POINTS

A few practical and valuable points in handling cases of presbyopia may be briefly noted. Tests for presbyopia must always be made with the distance corrections before the eyes. Too much dependence should not be placed in the all too numerous "rule-of-thumb" methods without due regard to all the data in the case under consideration. Glasses should be selected always with due regard to the uses to which they are to be subjected, as well as the length of the arms of the patient and the distance at which they prefer to work. Bookkeepers, carpenters, barbers and others in specialized trades or vocations should be furnished with a special correction for their daily work, as well as those for the customary reading distance. A reduction of about three-quarters of a diopter from the proper reading corrections ordinarily permits of satisfactory working conditions at arm's length.

The amount of reserve accommodation which it is necessary that the average eye possess in order to be comfortable is about 1.50 D. to 2.00 D. This, it is to be remembered, is but an average, for many persons can sustain comfortable vision at the customary reading distances with a reserve as low as one diopter. If, therefore, when reading at 13 inches, which requires an accommodation of 3 diopters, there is not present a reserve accommodation of 1.50 diopters—making a total amplitude of 4.50 diopters—then, regardless of the

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age of the patient, asthenopia or discomfort will usually follow continued reading or work at that distance.

And as Davis[74] says: "Each eye should be tested separately as well as both together for the near-point, for occasionally it will be found that the accommodative power, even where no paralysis of the accommodation is present, is different in the two eyes. This difference may amount to as much as one diopter, and in ordering the glasses this inequality should be taken into consideration. Finally, it must be said that no hard and fixed rule holds for prescribing glasses in presbyopia. Each patient must be fitted with the glasses that give the best vision at the distance desired for working."

[74]Davis, A. Edward. Section on Refraction and Accommodation of the Eye, *American Encyclopedia of Ophthalmology*, Vol. XIV, p. 10970. Cleveland Press, 1919.

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CHAPTER X

CROSS CYLINDER TESTS AND THEIR SIGNIFICANCE

THE correction of astigmatism enters into the majority of cases of refraction and a careful refractionist spends a considerable portion of the time he devotes to subjective testing in estimating the strength and axis of the astigmatic correction required. Various methods of determining the astigmatic axis may not be sufficiently prompt or reliable for refined work. Ordinary routine tests for astigmatism may well be supplemented, therefore, with a simple piece of apparatus, known as the cross cylinder, for the determination of both the axis and amount of astigmatism.

The cross cylinder test for the strength of astigmatic error was first described by E. Jackson.[75] The application of this same device for the determination of the axis was suggested by the same person nearly twenty years ago.[76] Yet it is safe to say that relatively few refractionists are familiar with either method. But few papers have appeared in the literature on this topic. The most recent are those by Schneideman[77], Crisp[78] and Wolff.[79]

The cross cylinder is a compound lens having a net minus strength in one principal meridian exactly equal to a net plus effect in the opposite principal meridian. In actual construction these are ground as sphero-cylindrical lenses:

[75]Jackson, E. Trial set of small lenses. *Transactions of American Ophthalmological Society*, Vol. IV, p. 595, 1885.

[76]Jackson, E. The astigmatic lens (crossed cylinder) to determine the amount and principal meridians of astigmia. *Ophthalmic Record*, p. 3781, 1907.

[77]Schneideman, T. B. The crossed cylinder in the determination of the refraction. *Ophthalmic Record*, p. 169, 1900.

[78]Crisp, W. H. A plea for the more general use of the cross cylinder. *American Journal of Ophthalmology*, Vol. VI, p. 209, 1923.

[79]Wolff, J. Cross cylinders in convergence tests. *American Journal of Physiological Optics*, Vol. V, p. 96, 1924.

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the minus axes are marked with white spots and the plus axes with red indicators. The values of the individual combinations vary in strength from −0.12D. cyl. ⊃ +0.12D. cyl. to +1.00D. cyl. ⊃ +1.00D. cyl. Their equivalents as sphero-cylindrical lenses are:

−0.12 D. S. ⊃ +0.25 D. cyl.
−0.25 D. S. ⊃ +0.50 D. cyl.
−0.50 D. S. ⊃ +1.00 D. cyl.
−0.75 D. S. ⊃ +1.50 D. cyl.
−1.00 D. S. ⊃ +2.00 D. cyl.

For general use the −0.25 D. cyl. ⊃ +0.25 D. cyl. and the −0.50 D. cyl. ⊃ +0.50 D. cyl. (or the second and third sphero-cylinders given in the above list) are employed and are included in the accessories supplied with the improved Phoroptor.

METHOD OF USE

The cross cylinder is not placed in the Phoroptor proper (or trial frame, if such is used in final subjective testing) but is held in front of it and the patient is given an *instantaneous* choice between two positions of the cross cylinder, the handle of which is rotated quickly between the examiner's thumb and index finger. Such a rotation obviously reverses the relative positions occupied by the plus and minus cylinders respectively.

In making the cross cylinder tests, the patient should not be asked, ordinarily, whether he sees better with the cross cylinder or without it. That which is needed is the choice between its two positions. Furthermore, Crisp[78] claims "that there is never any advantage in checking the cross cylinder for axis by means of the old-fashioned method of turning the cylinder in the trial frame" (or in the battery of cylindrical lenses of the Phoroptor) "in either direction until the patient decides that the vision is blurred".

As in all other astigmatic tests, the cross cylinder tests are more likely to be correct if the accommodation is relaxed and,

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therefore, the spherical element before the eye under test should be as strong a plus lens or weak a minus lens as barely to permit the patient to secure his full visual acuity.

Furthermore, the patient must base comparisons of the two positions of the cross cylinder upon an inspection of the lowest line of letters which he can partially or imperfectly read.

The cross cylinders may be used with great advantage in the following:

1 To determine the amount of astigmatism.

2 To locate the axis of the correcting cylinder.

3 As a dynamic procedure to determine whether accommodation and convergence are harmoniously balanced at the reading point.

4 For the determination of presbyopic corrections or comfortable reading additions.

The essential features of each of these procedures are presented in the paragraphs which follow.

I. TESTING THE STRENGTH OF THE CORRECTING CYLINDER

The cross cylinder is held with first one and then the other of its principal axes coincident with that of the cylinder in the Phoroptor, or, if there is no cylindrical correction present, coinciding with any axis in regard to which the presence or absence of astigmatism is to be determined. The patient, reading the lowest line of letters which he is able to read either partially or with difficulty, is asked to tell in which position (*i. e.* first or second) he is able the more readily to read the selected line as the cross cylinder is rotated, or turned by means of the handle held in the fingers, from one position to the other.

The selected preference of position of the cross cylinder indicates the general character of the change which should be made in the cylindrical correction. With minus cylinders as employed in the Phoroptor the power of the cylindrical correction will be increased when the minus cylinder of the cross cylinder is coincident with or superimposed upon the

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minus cylinder in the Phoroptor and will be decreased when the plus cylindrical element of the cross cylinder occupies this position. If, for example, the Phoroptor contains a -1.00 D. cyl. ax. 165 and the preferred position of the cross cylinder is that in which its minus axis is at 165°, the strength of the cylinder in the Phoroptor should be increased. The reverse would be true if the preferred position of the cross cylinder is that on which its plus element is in coincidence with the axis of the minus cylinder in the Phoroptor. If the original cylinder used is a plus one, the converse of the foregoing statements applies.

Such expressed preferences on the part of the subject under test do not necessarily indicate the exact increase or decrease required in the cylindrical power. After any increase or decrease has been made, the cross cylinder tests must be repeated. The criterion of proper correction is that the patient finds himself unable to read more letters with one position of the cross cylinder than with the other.

Crisp writes: "For 'roughing out' the strength of the cylinder required, this test is usually rapid and fairly accurate, especially if the patient is called upon each time definitely to determine the very lowest line on which any letters are legible; although with all cross cylinder tests, the patient often needs to be carefully warned that he may never see so distinctly with the cross cylinder before the eye as he does without it. In the final fractions, and where the axis of astigmatism is nearly or quite vertical or horizontal, the test for strength is sometimes fallacious, in that the patient tends to prefer the position of the cross cylinder which produces a vertical rather than a horizontal distortion of the letters. For this reason, after I have found the approximate or final axis . . . I usually prefer to work out the final fractions of astigmatic strength by means of the revolving cross type of astigmatic chart."[80]

[80]Crisp, W. H., *American Journal of Ophthalmology*, Vol. VI, p. 210, 1923.

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II. TO LOCATE THE AXIS OF THE CORRECTING CYLINDER

The cross cylinder test for locating the axis exactly is a more complicated procedure and is based on the fact that two cylinders of like denomination superimposed with their axes at an acute angle with one another create the equivalent of a new cylinder of different strength and with axis intermediate between the two axes of the separate lenses.

If, for example, the cylindrical correction before an eye is −1.00 D. cyl. axis 90, it may be desired to ascertain whether the axis should be shifted slightly nasally or temporally. If a cross cylinder, *i. e.* a −1.00 D. cyl. ⊂ +1.00 D. cyl., is held before the eye with its two axes at 45° with reference to the axis of the cylinder in the Phoroptor, and if the minus cylinder of the cross cylinder is at 45°, there is produced before the eye a new cylindrical effect at an axis midway between 90° and 135°, or 67.5°. If, on the other hand, the minus axis of the cross cylinder is at 135°, the resulting plus cylinder has its axis midway between 90° and 135°, or at 112.5°. If the axis of the patient's astigmatic error lies nearer 45° than 135°, while both positions of the cross cylinder may cause blur, the blur will be less pronounced when the cross cylinder is held with its minus axis at 45° than when it is held with its axis at 135°. If there is a preference in position of the cross cylinder, the axis of the minus cylinder correcting the astigmatism should be moved toward the preferred position of the minus axis of the cross cylinder. No exact information can be given on this point. It is moved a few degrees and then the tests are repeated and continued until a position of the correcting cylindrical lens is reached in which no preference is expressed and the patient is unable to read any more or any fewer of the letters with one position of the cross cylinder than with the other. This determines the correct axis of this correcting cylinder with a very considerable degree of accuracy.

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III. CROSS CYLINDERS IN CONVERGENCE TESTS

This may be called very appropriately the *dynamic* cross cylinder test. The method consists in placing before the eye a combination having the value -0.50 D. S. $\circ$ $+1.00$ D. cyl. with the plus axis horizontal. The chart to be used may be either one of those shown in Fig. 100, which are

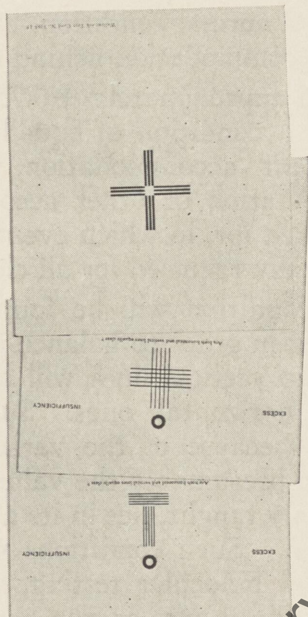

Fig. 100. Test cards for use in dynamic cross cylinder procedures

supplied with the Phoroptor. Or the examiner may use the very small set suggested by Wolff. The ametropic corrections for distant vision are to be in position before the eye under test and the test card is to be placed at the required reading distance, with the cross cylinder in the lens cell and with its plus axis horizontal. The patient is asked to state which group of lines, the vertical or horizontal, is the more distinct or blacker.

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It has been found that, in young subjects, and up to about forty years of age, a plus addition of approximately 0.75 D. to 1.00 D. will be shown; that is, the horizontal lines will appear the blackest and it will be necessary to add the above amount of plus lens to get an equalization. This corresponds to the average allowance made in making a dynamic skiametric examination of persons under the presbyopic age and represents a normal condition.[81] This is accounted for by the lag of accommodation behind convergence.

When more than approximately +0.75 D. S. is necessary in order to obtain a condition of equally black or blurred lines, an insufficient accommodation, latent hyperopia, spasm of accommodation or other accommodative abnormality is to be looked for, in which event additional convex lens power is generally required for all close work.

Occasionally a condition will be found in which minus spheres are required in order to balance the lines of the test chart. That is, the vertical lines will appear blacker and plainer than the horizontal ones. Such conditions are difficult to handle because of the variableness of accommodation, although presumably the value of the method, as it has been commonly taught, lies in its ability to inhibit accommodative action. Such conditions will be found, it is believed, only under binocular testing, in which case it is possible to explain the results on the basis of the fact that the patient is over-accommodating, possibly to help out a very weak convergence or to assist in overcoming a high exophoria at the reading or testing distance. Dynamic skiametric tests, together with the accommodative convergence and fusion convergence data, will furnish additional information in such cases.

As will be noted from the foregoing remarks, in all cases, after the proper amount of lens addition has been found monocularly, a binocular test should be made with a cross

[81] Wolff, J. *American Journal of Physiological Optics*, Vol. V, p. 100, 1924.

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cylinder placed before each eye. Vary the lenticular power to meet the demands of the eyes under these conditions by either increasing or decreasing the monocular findings.

IV. THE DETERMINATION OF PRESBYOPIC CORRECTIONS OR COMFORTABLE READING ADDITIONS

Suppose that a certain eye is being used at a distance of 16 inches, but that the near-point (wearing the full distance correction) is at 18 inches; this is clearly a case of *insufficient* accommodation. The near-point might be even closer, and yet, with due regard to the need of reserve accommodation, there would still be an insufficiency. But in the case where the patient is young, and the near-point, let us say, is at 8 inches—when the eyes are used at a distance of 16 inches the accommodation falls short because of a fairly faulty innervation to the ciliary muscle. Such a case is not truly presbyopic; it is one of *inefficiency* of the accommodation or pseudo-presbyopia. In either case the extra plus power that must be put before the eye to cause the accommodation to act in such a manner that there is neither an excess nor a deficit in its functioning, is a measure of the dynamic error of accommodation.[82] To get this measurement in each and every case and incidentally to discover how much accommodation must be kept in reserve in order to have theoretically perfectly comfortable vision for near work, one may use cross cylinders.

The technic of the method may be outlined as follows:

1 Set up the full distance correction and, if necessary for clear vision (presbyopic cases), add sufficient plus spherical power for the purpose.

2 Arrange the fixation card (Fig. 100) in the holder on the reading rod of the Phoroptor so that the sets of lines are truly horizontal and vertical.

[82]Lockwood, R. M. Cylinders and cross cylinders. *Optical Journal and Review*, Vol. XLIII, p. 955, 1901.

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3 Use, in general, the +0.50 D. cyl. $\supset$ −0.50 D. cyl. (*i. e.* +0.50 D. S. $\supset$ −1.00 D. cyl.) combination and place it before the eye under examination so that the axes of the cylinders agree with the direction of the arms of the T or the cross. Have the patient announce whether both sets of lines are seen equally clearly or whether there is a difference. If there is a difference and the lines agreeing in direction with the axis of the minus cylinder of the cross cylinder combination are clearest, the plus spherical power in the Phoroptor should be decreased until there is a balance. In any event changes in the power of the spherical lenses are to be made until equality of horizontal and vertical lines is obtained.

As previously noted, it has been found that, in young subjects, a plus addition of approximately 0.75 D. will be needed in order to obtain equality of sets of lines: that is, the horizontal lines will appear to be the blackest. In the case of presbyopes, however, the lag of accommodation becomes less and less with increasing years. As a result, therefore, one should make an allowance of about +0.50 D. S. for 50 years of age and of +0.25 D. S. for 60 years and practically no allowance from that age on.

In order to illustrate the principles involved in the dynamic use of cross cylinders we cite two examples:

Case 1 The refractive error is corrected by +1 00 D. S. $\supset$ +1.00 D. cyl. ax. 180°. Checked by cross cylinders with distant fixation the cylindrical finding remains unchanged.

The punctum proximum is at 8 inches. Using the dynamic cross cylinder method, an extra +0.75 D. S. is needed to give equality of lines on the near fixation chart (Fig. 100). The patient is 25 years of age; glasses have never been worn before. From the standpoint of the data furnished by the cross cylinder test it may be assumed that the distant findings will prove satisfactory also for close work and should be prescribed.

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Case 2 Distance correction is +0.75 D. S. No astigmatism, either at distant or near fixation points. The dynamic cross cylinder method shows that +1.50 D. S. must be added to produce equality of lines on the T or similar chart for near fixation. There is no trouble in distance vision, but headaches and blurring of letters occur in near work after an hour or so. The punctum proximum is at 7 inches. The patient's age is 40 years. In the face of these data only one would be tempted to prescribe +0.75 D. S. to +1.00 D. S. for close work only.

Lockwood further states that "the cross cylinder dynamic test can be used to differentiate between the forced and the comfortable amplitude of accommodation. To this end there should be a set of T charts, say three of them, one about a half the size of that shown in Fig. 100, one of the same size and one about twice as large. After the full distance correction has been determined and placed before the eye under test, the cross cylinder is added to it and the smallest T chart brought close to the eye and slowly withdrawn until both sets of lines become equally clear. If this does not happen by the time a distance of a foot is reached, the second-sized T chart should be substituted out to about two feet, and the large T chart used up to about 40 inches. Converted into diopters we get the amplitude of comfortable accommodation. If the equalizing point is still farther away, we increase the sphere in the frame (Phoroptor) by 1.00 D. and repeat the test, making allowance in the calculation for the 1.00 D. The forced accommodation is found in any of the usual ways. By comparing the two results, we get an idea of how much (theoretically) accommodation should be kept in reserve in the given case."

As examples of his method Lockwood cites the following illustrations:

"Case 1 With distance correction in place, the punctum proximum found in the usual way is at 7 inches, which

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equals 5.75 D. of amplitude. The punctum proximum found by the dynamic cross cylinder test is at 10 inches, which equals 4.00 D. The reserve accommodation in this case is 1.75 D."

"Case 2 The amplitude of accommodation found in the usual way is 7 D. By the cross cylinder dynamic test alone, the comfortable near point cannot be located. Adding a +1.00 D. S. to the correction it is not located at 26 inches. This distance is equal optically to 1.50 D., and making the allowance for the extra +1.00 D. S., this is reduced to 0.50 D. Hence, in this case, for perfect comfort, there should be a reserve of 6.50 D., which is markedly in excess of the usual average of one-third to one-half."

In conclusion, there are three facts in the refraction of presbyopic patients that should receive attention:

1 Many patients accept a weak plus cylinder (*e. g.* +0.50 D. cyl. ax. 180°) against the rule. This is presumptive evidence that the astigmatism is lenticular in character and may be due to sclerotic changes or to weakness of the Bowman's muscle. There is much evidence to support the statement that hyperopic eyes become more hyperopic after the age of 60 years, emmetropic eyes become hyperopic (gradually changing from +0.25 D. S. to +0.75 D. S. as the correction) and myopic eyes become less myopic, due to the same sclerotic or shrinking processes which take place in all ocular tissues as a result of senility. In cases in which astigmatism against the rule is found, and bifocal lenses are prescribed, care should be exercised in slightly undercorrecting the astigmatism, especially in view of the fact that the angling of correcting lenses of fair strength tends to introduce an equivalent plus cylinder at axis 180° if the correcting spheres are of a plus character.

2 An attack of glaucoma may precipitate presbyopic symptoms, so that if a presbyopic patient apparently requires frequent changes in his corrections, this complication should be borne in mind.

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3 The swelling of the crystalline lens which occasionally precedes the formation of some forms of cataract should be considered when the patient develops symptoms of such a nature as to require a reduction in the strength of the convex glasses worn.

Presbyopia is the one so-called "easy" ocular condition that is often the most difficult of satisfactory correction, for the reason that occupation, illumination, habit, pupillary size, muscular innervation and general bodily vigor are all factors which must be considered. Then if, combined with this, the ignorance and stupidity of many patients in answering questions is taken into account, it is not difficult to appreciate that presbyopic conditions demand the greatest skill and care.

The science and art of ocular refraction consist in the getting of data from as many different angles and by as many different methods as possible, so that these data may be analyzed and final judgments made as to what should be done in the best interests of the ocular economy and comfort of the person under examination.

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TABLES OF SCIENTIFIC DATA FREQUENTLY USED IN REFRACTION

FOCAL LENGTH

OPHTHALMIC lenses were originally designated by numbers which were the radii of curvature, to which each side was ground. These lenses were always biconvex,

TABLE OF FOCAL LENGTHS

Diopters	*Millimeters*	*Inches*
0.125	8000	315.00
0.25	4000	157.50
0.50	2000	78.70
0.75	1333	52.48
1.00	1000	39.37
1.25	800	31.50
1.50	667	26.24
1.75	571	22.48
2.00	500	19.68
2.50	400	15.75
3.00	333	13.12
4.00	250	9.84
5.00	200	7.87
6.00	167	6.54
7.00	143	5.63
8.00	125	4.92
9.00	111	4.37
10.00	100	3.94
11.00	90.9	3.58
12.00	83.3	3.28
13.00	76.9	3.03
14.00	71.4	2.81
15.00	66.7	2.62
16.00	62.5	2.46
17.00	58.8	2.32
18.00	55.6	2.19
19.00	52.6	2.07
20.00	50.0	1.97

or biconcave and, therefore, the numbers represented their approximate focal length. This was very inconvenient

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since the higher the number the weaker the lens; also the computation of two combined lenses, even approximately, was lengthy.

The next step was to designate the lens by its power, which is the reciprocal of its focal length in meters. As long as lenses were thin and not deeply curved, this was satisfactory. The power of the first surface could be added to the power of the second surface which would give a fair approximation to the power of the lens.

The simple formulæ connecting power (D.) and focal length (F.) power are:

$$F\ (\text{cm.}) = \frac{100}{D}$$

$$D = \frac{100}{F\ (\text{cm.})}$$

Modern developments of deep curve lenses and the increased precision of refraction have necessitated an exact system of designating power.

There are three ways of measuring the power of a lens and the one to be used is determined by the purpose of the lens. These are as follows:

1 Equivalent Focal Length

This is used for camera lenses as it determines the scale of the picture without regard to the distance of the film or plate from the camera.

2 Back Focal Length

This is an essential in determining the power of a lens as used in ophthalmic practice. The point of interest in ophthalmic practice is the distance from the cornea to the image plane formed by the lens. As the eye is at the rear of the ophthalmic lens, it is the back focal length which is of importance. Note that this distance may be approximate-

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ly what is given as the equivalent focal length of the lens, but in the telephoto lens, where the distance from the film to the lens is only about one-third of the equivalent focal length of the lens, the back focal length is only about one-third the equivalent focal length. The reciprocal of the distance from the rear surface of the lens to the back focal plane when measured in meters is what we call "effective power".

3 *Front Focal Length*

The system of front focal length is used in certain technical operations such as surveying, etc. It has been largely used for neutralization for two reasons. First, it was easy to do and, second, there was little error involved as long as the lenses were nearly symmetrical. Neutralizing a lens is exactly like placing it in front of a patient's eye, with the convex side towards the patient. There is one system of neutralization which is exact and that is to chip the neutralizing lenses down until they are about the size of a little fingernail and place them on the concave, or eye side of the lens. In this way the lenses will be measured or neutralized to the same power as the Lensometer. But one is interested in what happens on the eye side of the lens and not on the convex side, so if one changes the parallel light to the concave side, as is the case in the ordinary method of neutralization, one makes a serious error amounting in some cases to several diopters, although with ordinary weak lenses it is small.

Power of Lens Along the Axis

The reciprocal of the back focal length of a lens in meters is its effective power in diopters. The oblique effective power is along an oblique axis, passing through the center of rotation of the eye and is the reciprocal of the distance expressed in meters which separates the focus situated along this axis and a sphere, with a radius of 0.027 meters, concentric with the center of rotation of the eye and tangent to the ocular surface of the lens.

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Neutralization of lenses must be practiced with discrimination, if at all. The double convex lenses of the trial case are correctly neutralized by the master concave lenses. As a result, therefore, in the case of thick biconvex lenses, the curvatures are so modified that they give back focal lengths or possess effective powers which are correct and which are neutralized by the thin concave lenses. Toric lenses, however, cannot be exactly neutralized by double concave lenses, for either the front focal length will be obtained, or a false back focal length will be secured. Neither of these is desired in ocular practice.

Simple formulæ enable one to obtain the approximate effective power or vertex refraction, as well as the approximate neutralizing power of any ophthalmic lens in terms of the dioptric powers of the surfaces of the lenses, the thickness and the index.

Approximate Effective Power or Vertex Refraction $= D = D_1 + D_2 + .001\ s\ D_1^2$

Approximate Neutralizing Power $= D_N = D_1 + D_2 + .001\ s\ D_2^2$

in which D_N = approximate neutralizing power

D = approximate effective power

D_1 = surface of lens remote from eye

D_2 = surface of lens nearest eye

$$s = \frac{\text{thickness of lens in millimeters}}{\text{index of refraction}}$$

The accompanying table gives the equivalent, effective (vertex) and neutralizing powers of various forms and strengths of converging and diverging lenses.

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DIFFERENCE BETWEEN {EQUIVALENT POWER, EFFECTIVE ", NEUTRALIZING "} AND $(D_1 + D_2)$

Note.—To get power add quantities in table to (D_1+D_2)

Positives

D_1+D_2	Equivalent				Effective				Neutralizing				Thickness
	Bi-Convex	Con-vexo Plane	Meniscus $D_2=-3$	Meniscus $D_2=-6$	Bi-Convex	Con-vexo Plane	Meniscus $D_2=-3$	Meniscus $D_2=-6$	Bi-Convex	Con-vexo Plane	Meniscus $D_2=-3$	Meniscus $D_2=-6$	
0	0.00	0.00	+0.01	+0.03	0.00	0.00	+0.01	+0.03	0.00	0.00	+0.01	+0.03	1.2mm
+2	0.00	0.00	+0.02	+0.06	0.00	+0.01	+0.03	+0.08	0.00	0.00	+0.01	+0.05	1.9
+4	−0.01	0.00	+0.04	+0.10	+0.01	+0.03	+0.08	+0.17	+0.01	0.00	+0.01	+0.06	2.6
+6	−0.02	0.00	+0.06	+0.15	+0.02	+0.08	+0.17	+0.32	+0.02	0.00	+0.02	+0.08	3.1
+8	−0.04	0.00	+0.09	+0.22	+0.04	+0.17	+0.32	+0.53	+0.04	0.00	+0.02	+0.09	3.8
+10	−0.08	0.00	+0.12	+0.30	+0.08	+0.32	+0.55	+0.84	+0.08	0.00	+0.03	+0.11	4.6
+12	−0.12	0.00	+0.15	+0.37	+0.12	+0.52	+0.80	+1.16	+0.12	0.00	+0.03	+0.12	5.1
+14	−0.19	0.00	+0.19	+0.46	+0.19	+0.79	+1.18	+1.65	+0.19	0.00	+0.03	+0.13	5.7
+16	−0.28	0.00	+0.25	+0.57	+0.28	+1.18	+1.70	+2.30	+0.28	0.00	+0.03	+0.15	6.4
+18	−0.39	0.00	+0.30		+0.41	+1.68	+2.36	+3.12	+0.41	0.00	+0.03	+0.17	7.2
+20	−0.49	0.00			+0.51	+2.17	+2.91		+0.51	0.00	+0.03		7.3

Note—This table is based upon the first four terms of Formulae 4 and 6. Index, 1,500.

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Negatives

$D_1 + D_2$	Equivalent				Effective				Neutralizing				Thickness
	Bi-Concave	Plano-Concave	Meniscus $D_2 = +3$	Meniscus $D_2 = +6$	Bi-Concave	Plano-Concave	Meniscus $D_2 = +3$	Meniscus $D_2 = +6$	Bi-Concave	Plano-Concave	Meniscus $D_2 = +3$	Meniscus $D_2 = +6$	
0	0.00	0.00	+0.01	+0.03	0.00	0.00	+0.01	+0.03	0.00	0.00	+0.01	+0.03	1.2mm
−2	0.00	0.00	+0.01	+0.04	0.00	0.00	+0.01	+0.03	0.00	0.00	+0.02	+0.05	1.2
−4	0.00	0.00	+0.01	+0.04	0.00	0.00	+0.01	+0.02	0.00	+0.01	+0.04	+0.07	1.0
−6	−0.01	0.00	+0.01	+0.04	0.00	0.00	0.00	+0.02	+0.02	+0.02	+0.05	+0.08	0.7
−8	−0.01	0.00	+0.01	+0.04	+0.01	0.00	0.00	+0.02	+0.01	+0.03	+0.06	+0.09	0.7
−10	−0.01	0.00	+0.01	+0.05	+0.01	0.00	0.00	+0.02	+0.01	+0.05	+0.08	+0.13	0.7
−12	−0.01	0.00	+0.01	+0.05	+0.02	0.00	0.00	+0.02	+0.02	+0.07	+0.12	+0.17	0.7
−14	−0.02	0.00	+0.02	+0.06	+0.02	0.00	0.00	+0.02	+0.02	+0.09	+0.14	+0.20	0.7
−16	−0.03	0.00	+0.02	+0.07	+0.03	0.00	0.00	+0.02	+0.03	+0.13	+0.17	+0.24	0.7
−18	−0.04	0.00	+0.02	+0.07	+0.04	0.00	0.00	+0.02	+0.04	+0.17	+0.21	+0.29	0.7
−20	−0.05	0.00			+0.05	0.00	0.00	+0.02	+0.05	+0.20	+0.27		

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OBLIQUE CYLINDERS

It is sometimes necessary to know the power in either the horizontal or vertical meridian of an oblique cylinder. This is of special value in decentered lenses, where definite prism values are to be worn. If we determine the power of an oblique cylinder in the horizontal meridian then the prismatic effect in that meridian can be determined by the usual decentration formulæ using as the power, the algebraic sum of the spherical power, and the horizontal component of the cylindrical power. For the vertical meridian, use the algebraic sum of the spherical power and the vertical component of the cylindrical power.

If we call the cylindrical power A, and the axis θ then the horizontal component is $H = A \sin^2\theta$ and the vertical component is $V = A \cos^2\theta$.

The following table gives the horizontal component H and the vertical component V for 1.00 D. cylindrical power for every 5° of axis. For values other than 1.00 D. multiply the tabular values by the power of the cylinder.

HORIZONTAL AND VERTICAL COMPONENTS FOR +1.00 CYL. AXIS θ°

Angle	*Angle*	*H*	*V*
0°	180°	0.00	1.00 D.
5	175	0.01 D.	0.99
10	170	0.03	0.97
15	165	0.07	0.93
20	160	0.12	0.88
25	155	0.18	0.82
30	150	0.25	0.75
35	145	0.33	0.67
40	140	0.41	0.59
45	135	0.50	0.50
50	130	0.59	0.41
55	125	0.67	0.33
60	120	0.75	0.25
65	115	0.82	0.18
70	110	0.88	0.12
75	105	0.93	0.07
80	100	0.97	0.03
85	95	0.99	0.01
90	90	1.00	1.00

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TWO OBLIQUE CYLINDERS

At times one desires to know the equivalent sphero-cylinder effect of two oblique axis cylinders. This problem cannot be solved without the use of trignometric tables, but is not essentially difficult and without ambiguity when the following formuli are used.

Let the two cylinders be in the form

$$0.00 \text{ sphere} \supset \text{A cyl. axis } \alpha$$
$$0.00 \text{ sphere} \supset \text{B cyl. axis } \beta$$

Then determine φ, C, and C^1 from

$$\tan 2\varphi = \frac{A \sin 2\alpha + B \sin 2\beta}{A \cos 2\alpha + B \cos 2\beta}$$

$$C - C^1 = A \cos 2(\varphi - \alpha) + B \cos 2(\varphi - \beta)$$

$$C + C^1 = A + B$$

Then the transposed or equivalent sphero-cylinder is

$$C^1 \text{ sphere} \supset (C - C^1) \text{ cyl. axis } \varphi$$

PRISMATIC VALUES

A displacement of one centimeter is produced by a prism of one diopter value when the object is at a distance of one meter from the prism: two centimeters at a distance of two meters and six centimeters at a distance of six meters or twenty feet. The table gives data which are frequently of value to the refractionist.

TABLE OF PRISM DIOPTRIES AND ANGULAR DEVIATIONS

Prism Diopters	*Angle of Deviation*	*Prism Diopters*	*Angle of Deviation*
1	0° 34′.4	11	6 16 .7
2	1 8 .7	12	6 50 .7
3	1 43 .0	13	7 24 .3
4	2 17 .3	14	7 58 .2
5	2 51 .7	15	8 32 .0
6	3 26 .0	16	9 5 .3
7	4 0 .3	17	9 38 .9
8	4 34 .3	18	10 12 .3
9	5 8 .7	19	10 45 .3
10	5 42 .7	20	11 18 .7

[1] Carl Weiland. *Archives of Ophthalmology*, Vol. XXII, No. 4, 1893.

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METER-ANGLES

The unit of measurement of convergence is the meter-angle (Nagel), that is the amount of convergence that is necessary to fix an object at one meter's distance and in the median line. The value of the meter-angle is 1° 50′ for each eye if the interpupillary distance is 64 mm or twice that amount (3° 40′) for one eye if the object of fixation is directly in front of one eye.

TABLES OF VALUES OF METER-ANGLES

Meter Angle	*Angle of Deviation*	*Meter Angle*	*Angle of Deviation*
1	1° 43′.0	1	1°50′.0
2	3 26 .0	2	3 40 .0
3	5 8 .7	3	5 29 .0
4	6 50 .7	4	7 17 .7
5	8 32 .0	5	9 5 .3
P.D. = 60 mm		P.D. = 64 mm	

Since the meter-angle is a variable quantity when expressed in degrees (being dependent upon the interpupillary distance) Charles F. Prentice proposed the following rule, known as the

PRENTICE RULE

"Read the patient's interpupillary distance in centimeters, when one-half of it will indicate the prism dioptries required to substitute one meter-angle for each eye." If, then, the P. D. is 70 mm, or 7 cm, one-half of this is 3.5 and this number represents the number of prism dioptries equivalent of one meter-angle of convergence for each eye. The total convergence requirement for both eyes at one meter is, therefore, 7.0Δ.

DECENTRATION

It is a well-known fact that the decentration of a lens introduces prismatic power. Within certain limitations, this fact may be used in securing prismatic effects with ordinary lenses. The amount of decentration in centimeters is

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equivalent to the prismatic power (in prism dioptries) divided by the spherical power (in diopters). Or the prismatic effects in prism dioptries is equal to the spherical power in diopters multiplied by the decentration in centimeters.

If, therefore, D represents the dioptric power, P the prismatic effect and N the number of centimeters of decentration, we know that

$$D \times N = P$$
$$P \div D = N$$
$$P \div N = D$$

DECENTRATION OF SPHERICAL LENSES AND RESULTANT PRISMATIC EFFECTS

RESULTANT PRISM DIOPTERS

Lens Power in Diopters	1	2	3	4	5	6	7	8	9	10
				MILLIMETER DECENTRATIONS						
1	10.0	20.0								
2	5.0	10.0	15.0	20.0						
3	3.3	6.7	10.0	13.3	16.7	20.0				
4	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0		
5	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0
6	1.7	3.3	5.0	6.7	8.3	10.0	11.6	13.3	15.0	16.7
7	1.4	2.9	4.3	5.7	7.2	8.6	10.0	11.4	12.8	14.3
8	1.3	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.2	12.5
9	1.1	2.2	3.3	4.5	5.6	6.7	7.8	8.9	10.0	11.1
10	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
11	0.9	1.8	2.7	3.6	4.5	5.6	6.4	7.3	8.2	9.1
12	0.8	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3
13	0.8	1.5	2.3	3.1	3.8	4.6	5.4	6.2	6.9	7.7
14	0.7	1.4	2.1	2.9	3.6	4.3	5.0	5.7	6.4	7.1
15	0.7	1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.0	6.7
16	0.6	1.3	1.9	2.5	3.1	3.8	4.4	5.0	5.6	6.2
17	0.6	1.2	1.8	2.4	2.9	3.5	4.1	4.7	5.3	5.9
18	0.6	1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.6
19	0.5	1.1	1.6	2.1	2.6	3.2	3.7	4.2	4.7	5.3
20	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0

The direction of the decentration and the character of the lens (whether spherical or cylindrical; convex or concave) determine the direction of the base of the prism thus incorporated by decentration. These facts are summarized in the accompanying table.

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Lens	*Character*	*Direction of Decentration*	*Direction of Base of Prism*
Sphere	Convex	In Out Up Down	In Out Up Down
Sphere	Concave	In Out Up Down	Out In Down Up
Cylinder (Axis 90°)	Convex	In (right angles to axis) Out (right angles to axis) Up (along axis) Down (along axis)	In Out None None
Cylinder (Axis 180°)	Concave	In (along axis) Out (along axis) Up (right angles to axis) Down (right angles to axis)	None None Down Up

RESULTANT PRISMS

Whenever two prisms at right angles to each other are to be incorporated in a prescription, a resultant prism and angular position of its base-apex line can be easily determined. If V represents the vertical prism and H represents the horizontal prism, then the resultant prism, R, can be found from the simple formula that

$$R = \sqrt{V^2 + H^2}$$

The angular position of the base-apex line can be obtained from the formula that

$$V = H \text{ tangent } A°$$

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where A is the angle between the base-apex line of the resultant prism and the horizontal axis. The table given below gives a résumé of the prismatic values of the resultant prisms (R) and the angular positions (A°) of the base-apex line for various combinations of vertical and horizontal prisms.

HORIZONTAL PRISMS

VERTICAL PRISMS	0.50^Δ	1.00^Δ	1.50^Δ	2.00^Δ	2.50^Δ	3.00^Δ	3.50^Δ	4.00^Δ	4.50^Δ	5.00^Δ	6.00^Δ	7.00^Δ	8.00^Δ	9.00^Δ	10.00^Δ
0.50^Δ	0.71^Δ 45.0°	1.12 26.6	1.58 18.4	2.06 14.0	2.55 11.3	3.04 9.5	3.54 8.1	4.03 7.1	4.53 6.3	5.02 5.7	6.02 4.8	7.01 4.1	8.02 3.6	9.01 3.2	10.01 2.9
1.00^Δ	1.12 63.4	1.41 45.0	1.80 33.7	2.24 26.6	2.69 21.8	3.16 18.4	3.64 15.9	4.12 14.0	4.61 12.5	5.10 11.3	6.08 9.5	7.07 8.1	8.06 7.1	9.06 6.3	10.05 5.7
1.50^Δ	1.58 71.6	1.80 56.3	2.12 45.0	2.50 36.9	2.92 31.0	3.35 26.6	3.81 23.2	4.27 20.6	4.74 18.4	5.22 16.7	6.18 14.0	7.16 12.1	8.14 10.6	9.12 9.5	10.11 8.5
2.00^Δ	2.06 76.0	2.24 63.4	2.50 53.1	2.83 45.0	3.20 38.7	3.61 33.7	4.03 29.7	4.47 26.6	4.92 24.0	5.39 21.8	6.32 18.4	7.28 15.9	8.25 14.0	9.22 12.5	10.20 11.3
2.50^Δ	2.55 78.7	2.69 68.2	2.92 59.0	3.20 51.3	3.54 45.0	3.91 39.8	4.30 35.5	4.72 32.0	5.15 29.1	5.59 26.6	6.50 22.6	7.43 19.7	8.38 17.4	9.34 15.5	10.31 14.0
3.00^Δ	3.04 80.5	3.16 71.6	3.35 63.4	3.61 56.3	3.91 50.2	4.24 45.0	4.61 40.6	5.00 36.9	5.41 33.7	5.83 31.0	6.71 26.6	7.62 23.2	8.54 20.6	9.49 18.4	10.44 16.7
3.50^Δ	3.54 81.9	3.64 74.1	3.81 66.8	4.03 60.3	4.30 54.5	4.61 49.4	4.95 45.0	5.32 41.2	5.70 37.9	6.10 35.0	6.95 30.3	7.83 26.6	8.73 23.6	9.66 21.3	10.59 19 3
4.00^Δ	4.03 82.9	4.12 76.0	4.27 69.4	4.47 63.4	4.72 58.0	5.00 53.1	5.32 48.8	5.66 45.0	6.02 41.6	6.40 38.7	7.21 33.7	8.06 29.7	8.94 26.6	9.85 24.0	10.77 21.8
4.50^Δ	4.53 83.7	4.61 77.5	4.74 71.6	4.92 66.0	5.15 60.9	5.41 56.3	5.70 52.1	6.02 48.4	6.36 45.0	6.73 42.0	7.50 36.9	8.32 32.7	9.18 29.4	10.06 26.6	10.97 24.2
5.00^Δ	5.02 84.3	5.10 78.7	5.22 73.3	5.39 68.2	5.59 63.4	5.83 59.0	6.10 55.0	6.40 51.3	6.73 48.0	7.07 45.0	7.81 39.8	8.60 35.5	9.43 32.0	10.30 29.0	11.18 26.6
6.00^Δ	6.02 85.2	6.08 80.5	6.18 76.0	6.32 71.6	6.50 67.4	6.71 63.4	6.95 59.7	7.21 56.3	7.50 53.1	7.81 50.2	8.49 45.0	9.22 40.6	10.00 36.9	10.82 33.7	11.66 31.0
7.00^Δ	7.01 85.9	7.07 81.9	7.16 77.9	7.28 74.1	7.43 70.3	7.62 66.8	7.83 63.4	8.06 60.3	8.32 57.3	8.60 54.5	9.22 49.4	9.90 45.0	10.63 41.2	11.40 37.9	12.21 35.0
8.00^Δ	8.02 86.4	8.06 82.9	8.14 79.4	8.25 76.0	8.38 72.6	8.54 69.4	8.73 66.4	8.94 63.4	9.18 60.6	9.43 58.0	10.00 53.1	10.63 48.8	11.31 45.0	12.04 41.7	12.81 38.7

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The upper figure in each of the squares indicates the value of the resultant prism while the second figure gives the angular position of the resultant prism.

The reader, however, should remember that the horizontal prisms may be either base in or base out, and the vertical prism may be either base up or base down. As a result, therefore, prism, base in, is either O. D. base-apex line 0° or O. S. base-apex line 180°. In turn, prism, base out, is either O. D. base-apex line 180° or O. S. base-apex line 0°. Prism, base up, is base-apex (B. A.) line 90° and prism, base down, is base-apex line 270°. These facts must be borne in mind when specifying the correct angular position of the base-apex line.

To illustrate, we give two examples:

(1) O.D. 2Δ, base in $\subset$ 1.0Δ base up
or 2Δ, B. A. 0° $\subset$ 1.0Δ, B.A. 90°

(2) O.S. 2Δ, base in $\subset$ 1.5Δ base down
or 2Δ, B. A. 180° $\subset$ 1.5Δ, B. A. 270°

The resultant prisms are:

(1) O.D 2.24Δ, B.A. 26.6°
(2) O.S. 2.50Δ, B.A. 216.9° (*i.e.* 270°—53.1°).

HYPEROPIC AND MYOPIC CORRECTIONS AT THE CORNEA

The power of a correcting lens at a distance from the cornea differs from the actual power which would be required if that lens were placed in contact with the cornea.

The following brief table gives the effective power of a lens at 14 mm from the cornea which is required to produce a given correction at the cornea of the eye.

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HYPEROPIA		MYOPIA	
Corneal Correction in Diopters	*Effective Power of Correcting Lens*	*Corneal Correction in Diopters*	*Effective Power of Correcting Lens*
+0.50 D.	+0.50 D.	−0.50 D.	−0.50 D.
+1.00	+0.99	−1.00	−1.01
+1.50	+1.47	−1.50	−1.53
+2.00	+1.95	−2.00	−2.06
+2.50	+2.42	−2.50	−2.59
+3.00	+2.88	−3.00	−3.13
+3.50	+3.34	−3.50	−3.68
+4.00	+3.79	−4.00	−4.24
+5.00	+4.67	−5.00	−5.38
+6.00	+5.53	−6.00	−6.55
+7.00	+6.37	−7.00	−7.76
+8.00	+7.13	−8.00	−9.01
+9.00	+7.99	−9.00	−10.30
+10.00	+8.77	−10.00	−11.63
+11.00	+9.53	−11.00	−13.00
+12.00	+10.27	−12.00	−14.42
+13.00	+11.00	−13.00	−15.89
+14.00	+11.71	−14.00	−17.41
+15.00	+12.40	−15.00	−18.99

Corneal distance is assumed to be 14 mm.

Very approximately, one millimeter change in depth of the eye corresponds to a dioptric change of 3.00 D. Or, in other words, if the edge of the optic disc is seen through a +4.00 D. S. and the bottom of the disc is seen with a −2.00 D. S., the accommodation being relaxed, the depth of the cup may be estimated as being 2 mm.

A change of one millimeter in the radius of curvature of the cornea corresponds to a refractive difference of approximately 6.00 D. If the power in one principal meridian of the eye is 45 D. and in the other principal meridian is 51 D., the examiner may conclude that the radii of curvature differ by one millimeter.

ACCOMMODATION

It is a well recognized fact that the accommodative power decreases with advancing years. While there is no exact

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relationship between age and accommodation which will hold for all individuals, the following table shows approximately the change that is to be expected.

ACCOMMODATION AND AGE

Age in Years	*Accommodation in Diopters*	*Near Point in Centimeters*
10	14	7.1
15	12	8.3
20	10	10.0
25	8.5	11.7
30	7	14.3
35	5.5	18.2
40	4.5	22.2
45	3.5	28.6
50	2.5	40.0
55	1.5	66.7
60	1.0	100.0
65	0.5	200.0
70	0	——

TRANSPOSITION OF LENSES

The transposition of a prescription from its original form is frequently desirable, especially in view of the fact that lens manufacturers and manufacturing opticians follow certain rules in the making-up of various prescriptions in toric form. The rule for transposition is:

Add together algebraically the spherical and cylindrical powers for the new sphere; then change the sign of the cylinder and change its axis 90 degrees. The new cylinder has the same power as that of the original cylinder.

A few examples will illustrate the operation of the rule.

+4.00 D.S. ⊂ +2.00 D. cyl. ax. 20°
= 6.00 D. S. ⊂ −2.00 D. cyl. ax. 110°

−2.50 D. S. ⊂ −1.50 D. cyl. ax. 175°
= −4.00 D. S. ⊂ +1.50 D. cyl. ax. 85°

+3.50 D. S. −2.50 D. cyl. ax. 45°
= +1.00 D. S. ⊂ +2.50 D. cyl. ax. 135°

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$+3.00$ D. S. ○ -3.00 C. cyl. ax. 180°
 = $+3$ D. cyl. ax. 90°

-1.25 D. S. ○ $+1.75$ D. cyl. ax. 160°
 = $+0.50$ D. S. ○ -1.75 D. cyl. ax. 70°

$+2.00$ D. cyl. ax. 80° ○ $+3.00$ D. cyl. ax. 170°
 = $+2.00$ D. S. ○ $+1.00$ D. cyl. ax. 170°
 or = $+3.00$ D. S. ○ -1.00 D. cyl. ax. 80°

EFFECTIVE POWER OF A SPECTACLE LENS

In general two or more lenses separated by air spaces do not have the combined power which is the sum of each taken separately. This is due to two causes. First, to the separations between the lenses and secondly to the successive refractions which take place at each lens before the light enters the next lens. A system of lenses which can be added to give the effective power of the combination is called an "additive" system.

A unique feature of the Wellsworth DeZeng Improved Phoroptor Model 588 is the compensation for the sequence of lenses as well as their positions covered by patent No. 1,455,457, E. D. Tillyer assigned to American Optical Company. As a result, therefore, the álgebraic sum of all lenses placed in the Phoroptor before the eye under test is equal to the effective power of a single lens of the same value placed at 13.75 mm from the cornea, provided the Phoroptor is properly placed during test, that is with the ocular plane of the eyecups tangent to the cornea. As a result, the examiner has the correct effective power required by the patient. To obtain the equivalent of this desired effective power in the best form of ophthalmic lens is a problem for specialists in the theory of lenses.

EFFECT OF POSITION

While the effective power of an ophthalmic lens cannot be changed, the correction at the cornea may be altered by reason of its position before the eye. If the distance of

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the test lens from the cornea is 14 mm and the prescription lens is placed at some other distance then the correction at the cornea is altered. In the last analysis, therefore, especially in prescribing high corrections, the examiner is desirous of having the final lenses worn by the patient such as to give the same effectivity as did his trial lenses. He must, therefore, take into account the distance from the cornea at which the final lenses are to be worn by the patient if it differs from the standard 13.75 mm.

It is a well-known fact that the movement of a convex lens away from the eye increases the correction at the cornea, while the same movement of a concave lens decreases this correction. The change in effectivity (C) due to the altered position of a lens is obtained from the simple formula

C = change in effectivity = $.001\ s\ D^2$

in which s = distance lens is moved in millimeters

D = dioptric power of lens

This is of great importance in cataract and high myopic cases. A shift of 3 mm forward from the eye in the case of a +14 D. S., for example, gives this +14 D. S. an increase in power, insofar as the eye is concerned, of 0.6 diopter, or is equivalent to +14.6 D. at the original position.

The improved Phoroptor automatically takes care of one of the difficulties of modern ophthalmic lenses in that it provides the examiner with the exact effective power needed by an eye if the final lens is worn at 14 mm from the eye. If another position is chosen, the change in the effective power to be ordered is given by the simple formula

$$C = .001\ s\ D^2$$

If, for example, a correction of +10.00 D. S. is obtained with the improved Phoroptor at a distance of 14 mm and it is desired to have the final lens worn at 10 mm from the eye, then one must find the change in effectivity. This is given as C = .001 x 4 x 100 or 0.4 D. Hence the lens to be ordered should have an effective power of 14.4 D.

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The reader is referred to articles by A. Estelle Glancy on the "Power of a Spectacle Lens" (*American Journal of Physiological Optics*, Vol. 2, p. 71, 1921) and by Charles Sheard on "Some Fundamental Principles of Ophthalmic Lenses" (*American Journal of Physiological Optics*, Vol. 6, p. 32, 1925), as well as the article on "Neutralization, Effective Power and Vertex Refraction of Cataract Lenses" (*American Journal of Physiological Optics*, Vol. 7, p. 548, 1926); also paper in *American Journal of Ophthalmology*, Vol. VII, p. 597, 1924.

See American Optical Company book of Instructions for use of Lensometer, for the origin of the formula

$$C = 0.001 \text{ s } D^2$$

The reader can also find an excellent historical sequence of steps by which effective power has become established in "Recommendations concernant La Lunetterie" in the Revue d'optique theorique et instrumentale, tome 4 (1925) pages 332–339 and 390–395.

"Il restait néanmoins a définir les puissances obliques. A ce sujet, la Commission s'ést référée aux définitions données par l' American Optical Company, et, après examen approfondi, les a approuvées.

"Elle a alors émis le voeu suivant, qui a clos la discussion relative a la définition de la puissance pour les verres a faces sphériques.

VOEU

"*Puissance des verres de lunetterie. Les puissances seront exprimées en dioptries frontales.* (*effective power*)*

"*La puissance en dioptries frontales est l'inverse de la distance, exprimée en metres, qui sépare le foyer image du sommet de la face du verre du coté de l'oeil.*

"*La puissance optique frontale suivant un axe oblique passant par le centre de l'oeil est l'inverse de la distance, exprimées en metres, qui sépare le foyer image situé sur cet axe d'une sphére concentrique a l'oeil et tangente au sommet de la surface du verre du coté de l'oeil. On suppose le centre de l'oeil sur l'axe optique et a 27 mm de la surface du verre.*"

**The parenthesis is inserted by the author.*

(Translation)

The Commission investigated the definitions of oblique powers given by the American Optical Company and after an exhaustive examination approved and adopted them. The Commission closed the discussion relative to the definition of spherical lens powers, and made the following resolution.

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RESOLUTION

Power of Spectacle Lens. The power will be expressed in effective power. The effective power of a lens is the reciprocal of the distance expressed in meters of the focal plane from the ocular surface of the lens. The oblique effective power is measured along an oblique axis passing through the center of rotation of the eyeball and is the reciprocal of the distance expressed in meters from a sphere concentric to the eye and its surface tangent to the ocular surface of the lens, to the focus on this oblique axis. The distance from the center of the eyeball being taken as 27 mms.

In this work the definition of oblique effective power as defined by the American Optical Company is standard for *France*.

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